COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 11-1		FOR NSF USE ONLY
NSF 12-524	03/21/12	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)		
DEB - Long-Term Ecological Research		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				173851965	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY?
856000401	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
New Mexico State University	New Mexico State University Corner of Espina St. & Stewart Las Cruces, NM. 880038002
AWARDEE ORGANIZATION CODE (IF KNOWN) 0026575000	
NAME OF PRIMARY PLACE OF PERF	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
New Mexico State University	New Mexico State University 2995 Knox St Las Cruces ,NM ,880030003 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS
☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **LTER: Long-Term Research at the Jornada Basin (LTER-VI)**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 5,880,000	72 months	11/01/12	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ______
PHS Animal Welfare Assurance Number ______
☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number ______
Exemption Subsection ______ or IRB App. Date ______
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
______
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
Jornada Experimental Range	MSC 3JER, Box 30003 Las Cruces, NM 88003 United States
PI/PD FAX NUMBER 575-646-5889	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Debra P Peters	PhD	1988	575-646-2777	debpeter@nmsu.edu
CO-PI/PD Brandon Bestelmeyer	PhD	2000	575-646-5139	bbestelm@nmsu.edu
CO-PI/PD Stephanie V Bestelmeyer	PhD	2000	575-524-3334	stephanie@asombro.org
CO-PI/PD Kris M Havstad	PhD	1981	575-646-4842	khavstad@nmsu.edu
CO-PI/PD Hugh C Monger	PhD	1990	505-646-1910	cmonger@nmsu.edu

PROJECT SUMMARY

Intellectual merit: Chihuahuan Desert landscapes exemplify the ecological conditions, vulnerability, and management challenges in arid and semi-arid regions around the world. The goal of the Jornada Basin Long Term Ecological Research program (JRN LTER) established in 1982 is to understand and quantify the key factors and processes controlling ecosystem dynamics and patterns in Chihuahuan Desert landscapes. In collaboration with the Jornada Experimental Range (USDA ARS), studies initiated in 1915 have been incorporated into the JRN LTER program. Previous research focused on desertification, a state change from perennial grasslands to woody plant dominance that occurs globally. Based on findings from growing long-term databases, the breadth of studies was expanded to include four additional state changes that occur in dryland systems worldwide: (1) a reversal to grassland states, (2) transitions among different states dominated by woody plants, (3) invasion by non-native grasses leading to novel states, and (4) transitions to human-dominated states. Processes of interest include water mediated plant-soil feedbacks, patch-scale contagion, landscape context, and time lags that are manifested as nonlinear dynamics and threshold behavior. ***The overall goal of Jornada LTER-VI (2012-2018) is to understand and quantify the mechanisms that generate alternative natural and human-dominated states in dryland ecosystems, and to predict future states and their consequences for the provisioning of ecosystem services.*** A modified conceptual framework and integrated research plan in LTER-VI will be used to: (1) test specific elements by coupling existing long-term studies of patterns with new experiments aimed at elucidating processes, (2) integrate data from long-term studies in novel ways to address new questions, both at the JRN and in the surrounding region, and (3) forecast alternative future landscapes and consequences for ecosystem services under a changing environment. The proposed research is organized around two major geomorphic units that characterize the Chihuahuan Desert, and that contain on-going long-term studies and a sensor network. Long-term studies will be combined with new mechanistic experiments designed to identify dominant processes and drivers with a focus on pattern-process relationships that transcend scales. The generality of this framework will be assessed with cross-site and regional studies. Simulation modeling will be used to synthesize and integrate data, both to understand current patterns and to predict future dynamics. New socio-economic studies and scenarios based on the Ecosystem Millennium Assessment will place Jornada research into a broader socio-economic-ecologic context. **Proposed research will result in five major products:** (1) new understanding of state changes, in particular in drylands, that lead to theory development, testable hypotheses, and new experiments; (2) accessible data and visualization tools applicable at multiple scales; (3) explanatory and predictive relationships between drivers, patterns, and processes that can be used to (4) develop scenarios of alternative human- and natural-dominated states with assessments of their impacts on ecosystem services; and (5) usable information transfer to a broad audience including K-12 students and teachers, and NGO and government agency land resource managers.

Broader impacts: Training opportunities will be provided for a large number of graduate and undergraduate students, primarily from New Mexico State University, a Hispanic-serving institution. International collaborations will include cooperative agreements with research and academic institutions on five continents (North and South America, Asia, Europe, Australia). JRN LTER research supports a highly successful K-12 and teacher training program: over 60,000 students, teachers, and other adults were involved in educational outreach programs during LTER V. The majority of participants are from underserved populations from southern New Mexico and west Texas: ca. 80% are classified as "economically disadvantaged," and 75% are Hispanic. These programs will continue to include inquiry-based science education curricula, field trips, schoolyard ecology activities, teacher workshops, and public education events. Interactions with resource management practitioners will occur via workshops, seminars, and service by LTER scientists on various boards of directors. The JRN LTER annual research symposium is attended by > 100 scientists, educators, and land managers. A periodic newsletter is available on the JRN LTER web page and is distributed to > 300 people.

1. RESULTS FROM PRIOR NSF SUPPORT

Peters, DPC, KM Havstad, HC Monger, and BT Bestelmeyer. Jornada Basin LTER V: Linkages in semi-arid landscapes. 2006-2012. $4,920,000 (DEB 06-80412)

1. Productivity and datasets. The quantity of our publications has increased through time with a combined average of >44 papers, book chapters, and proceedings a year, and a total-to-date for LTER-V (1-1-2012) of 198 journal articles, 70 book chapters and proceedings, 16 theses and dissertations, and 9 books since 2006 (see full listing at: http://jornada-www.nmsu.edu/site/pubs/biblio/JRN_LTER-V_pubs.pdf). We published in high visibility/impact journals, including *Trends in Ecology and Evolution, Science, BioScience*, *Frontiers in Ecology and Evolution*, *Global Change Biology*, and *Ecology*. Our 10 most significant publications (shown in ***bold italics*** below and summarized in Table 1.1) were selected based on: impact on Jornada research development, significance to drylands research, contribution to ecological theory and general understanding of ecological systems, and impact on land management. Our database contains ca. 264 data sets derived from studies representing all five core areas. Core study name abbreviations are shown in italics below with accessibility details of datasets found in Suppl. Table A1 (summary found at http://jornada-www.nmsu.edu/stats/LTERV/data_web_access_statistics.php). On average, one or more of our data sets are accessed more than 238 times per month. Our homepage is accessed an average of 446 times per week by non-Jornada associated computers. 99% of our core long-term datasets are available online and the other 1% require permission of the responsible investigator.

2. Conceptual framework. We continue to test and define our conceptual framework for disentangling complex landscapes, such as those in arid regions (***Peters et al. 2006***). Our framework builds on the previous Jornada resource redistribution framework (Schlesinger et al. 1990) at the plant-interspace scale by including multiple scales of interaction and five key components (Fig. 2.1). The framework was expanded to compare connectivity in diverse ecosystems (***Okin et al. 2009b***) and to link scales in a soils-based hierarchy (***Monger et al. 2009a***). This unifying framework is being used to integrate our existing short- and long-term studies (detailed in Suppl. Table A1) and to guide our proposed experiments in LTER-VI. This cross-scale framework was used by other LTER and non-LTER sites to explain dynamics in other systems, including temperate and tropical forests, barrier islands, and metapopulations of animals (Peters et al. 2007 and other papers in the *Ecosystems* Special Feature). We also expanded the framework to explain regional and continental-scale dynamics that contributed to the design of NEON (***Peters et al. 2008*** and other papers in the *Frontiers in Ecology and the Environment* Special Issue).

3. Grassland-to-shrubland transitions. We focused on resolving the sequence of processes involved in state change from grasslands to shrublands, including the initiation of state change, the mechanisms maintaining the shrubland state and promoting its expansion, and the distribution of state change at broad spatial scales. The initiation and consequences of state transition for black grama production, based on historical data, used an approach for the analysis of abrupt transitions common with other LTER sites ***(Bestelmeyer et al. 2011a)***. Feedbacks and shrub adaptations are likely to be responsible for the transition and maintenance of shrubland states (Okin et al. 2009b, Throop et al. 2012, D'Odorico et al. 2012). Spatial factors mediate the pattern of grasslands and shrublands (Bestelmeyer et al. 2011b), and time series of MODIS NDVI data was used to detect state changes at landscape scales (Williamson et al. 2012). These results were used to inform management tools and policy interpretations by agencies within the US and internationally (Archer et al. 2011, ***Bestelmeyer et al. 2009***; 2011c).

4. Shrubland-to-grassland transitions. Initial studies of these reversals using simulation modeling showed that perennial grass recruitment following shrub invasion is dependent on location-specific changes in soil properties and vegetation cover (Peters et al. 2010). These results identified the spatial locations and temporal conditions where remediation efforts are likely to be successful, and guided the design of a pilot study of cross-scale interactions (*ConMod*) that was recently expanded to a full experiment (*Xscale*). Long-term observations of aboveground net primary production (*NPP*) show that 5 consecutive wet years can lead to perennial grass recovery in desertified shrublands (Peters et al. 2012b). Integrating multiple datasets (*Phenology, Jornex, NPP*) showed that a sequence of demographic processes occurred through time to result in grass recovery (Peters et al. submitted).

5. Carbon and nitrogen. Carbon isotope studies combined with erosion rates revealed that prehistoric shifts from C_4 to C_3 vegetation were related to a change from semiarid to arid climate, especially when pedogenic carbonates were present (Liu et al. 2007, Kraimer and Monger 2009, ***Monger et al. 2009a).*** Long-term water redistribution studies showed that runoff areas (i.e., bajada landforms) are more susceptible to shrub encroachment compared with runon areas (Weems and Monger 2012). These ecological effects of runoff-runon and soil water holding capacity (***Duniway et al. 2010a***) are also prevalent in other deserts (Williams et al. 2008, Monger et al. 2011). Our litter decomposition studies suggest that soil-litter mixing, a function of vegetative cover patterns, can negate photo-degradation to affect formation of stable soil aggregates (Barnes et al. 2012). These results illustrate the role of soil coverage in mediating ultraviolet radiation-microbial interactions during litter decomposition (Throop and Archer 2007; 2009).

6. Plant-animal interactions. The response of rodent biomass to rainfall is strongly contingent on shrub dominance and is nonlinear: large increases in formerly rare species and population crashes are common (*SMES*) (Lightfoot et al. 2008). We documented experimentally that black grama seedling establishment may be increasingly limited by rodents as shrubs increase in dominance (*Ecotone*) (Bestelmeyer et al. 2007, Kerley and Whitford 2009, Roth et al. 2009). This animal-mediated feedback may contribute to grass loss with shrub invasion. By comparing ant communities in areas with different plant composition and ANPP, we found that ant biomass is invariant, but community composition shifts to species capable of accessing homopteran exudates in shrublands (Rios-Casanova and Bestelmeyer 2008). Long-term studies documented the importance of small animals for soil water infiltration, soil chemistry, soil microbial communities, annual plants, shrub mortality, and the persistence of desertified states (Roth et al. 2007, Duval and Whitford 2008, James et al. 2008, Eldridge and Whitford 2009, Eldridge et al. 2009, Whitford et al. 2008, Whitford and Steinberger 2010, Whitford et al. 2012).

7. Soil-plant-water interactions. Contrary to previous studies, we found that petrocalcic horizons, a rock-like soil horizon common on the Jornada and in desert ecosystems globally, have the capacity to absorb and retain large amounts of plant available water (PAW) (Duniway et al. 2007). Petrocalcic soils are recharged by winter and summer rains, and retain large amounts of PAW for extended time periods (***Duniway et al. 2010a***). Studies also showed that soil water under mesquite may not limit grass recovery (Duniway et al. 2010c). Long-term (1937-2008) image analysis of neighboring soils with either deep or shallow to petrocalcic horizons revealed that, although both soils had similar initial plant composition, different demographic responses to PAW by depth resulted in a shrub-dominated state on the deep soil and a mixed shrub-grass state on the shallow soil (Browning and Duniway 2011, Browning et al. 2012).

8. Ecohydrology. A spatially-explicit, integrated field and modeling experiment commenced in 2010 in a watershed within the mixed shrubland bajada geomorphic unit. Initial results showed that horizontal variation in soil moisture measurements improve the characterization of the watershed-scale water balance and ecosystem evapotranspiration compared with traditional approaches (Templeton 2011). Eddy covariance observations showed that land-atmosphere fluxes during the North American monsoon are linked to soil moisture and vegetation phenology. Spatial variability in soil moisture and runoff correspond to hillslope and channel infiltration properties, and in particular, depth to the calcium carbonate layer. Phenological analyses from field observations (*Phenology*) and Unmanned Aerial Vehicle (UAV) imagery showed species-specific responses to seasonal rainfall and soil moisture availability (Browning et al. 2011, ***Laliberte et al. 2010***). Field sampling, sensor network, and remote sensing observations are being integrated with watershed simulations using the Triangulated Irregular Network-based Real-time Integrated Basin Simulator (tRIBS) to explore the spatial organization of ecohydrological systems.

9. Aeolian dynamics. In a large-scale grass removal experiment (*NEAT*), we identified several important thresholds that impact the conversion of grasslands to shrublands. Between 75%-100% grass loss, aeolian transport increases dramatically, but carbon and nitrogen in windborne sediment display another threshold between 50%-75% grass loss (Li et al. 2007). With lower grass cover, nutrient additions to the soil are overwhelmed by aeolian emissions, resulting in a net loss of soil nutrients (Li et al. 2008). The sediment that is deposited downwind of the vegetation is both coarser (Li et al. 2009b) and lower in nitrogen (Li et al. 2009a) than the source sediment. Increased aeolian sediment flux downwind decreases grass cover and increases shrub cover (Alvarez et al. 2011). Wet years increased competition among grasses and decreased competition between grasses and shrubs (Alvarez et al. 2012). These data were used to develop and validate a model of aeolian sediment flux (Okin et al. 2006, Okin 2008).

10. Disturbance. In collaboration with the Bureau of Land Management (BLM), we found that fire is more likely to kill small black grama plants, and reduce basal area of larger plants (Drewa et al. 2006). A pulse of livestock overgrazing that reduced black grama cover to <3% resulted in very little recovery even 10 years after grazing ceased *(MSE*). Results of USDA-LTER collaborative research showed that roads and off-road vehicles commonly impact hydrologic function, and soil and site stability, including susceptibility to wind and water erosion (Duniway et al. 2010b, Duniway and Herrick 2011). We defined elements to systematically predict, assess, and minimize road impacts (Duniway and Herrick 2011). We also presented a framework for quantitative comparisons of disturbance effects across different types of ecosystems and multiple LTER sites (Peters et al. 2011b).

11. Simulation modeling. We used a multi-layer model of soil water dynamics to simulate effects of transitions from grasslands to shrublands to black grama recruitment across the Jornada (Peters et al. 2010). We used resource selection functions to compare foraging behavior of a heritage breed of cattle from Mexico (Criollo) with a commonly used introduced European breed (Angus) as a first step in adding cattle as transport vectors to our ENSEMBLE model (Peinetti et al. 2011). We used a model of aeolian sediment flux to simulate effects of alternative vegetation structure on dust flux (Okin et al. 2006; Okin 2008). We combined the tRIBS model with high-resolution datasets to address hydrologic connectivity and its impact on state changes at a range of scales (Vivoni 2012).

12. Socio-ecological systems. We initiated studies of coupled human-natural systems through data acquisition and mapping of socioeconomic variables in selected areas of southern NM where we documented: changes in land cover classes and land fragmentation through time, trends in land ownership, and historical linkages among climatic drivers, management decisions, and transitions from grasslands to shrublands (Buenemann and Wright 2010, Skaggs et al. 2011).

13. Synthesis, cross-site, and network-level activities. The publication of our LTER Synthesis book provided a key synthesis of past and present research (***Havstad et al. 2006***). We also published a special issue of 10 papers in the *Journal of Arid Environments* that focused on research associated with our conceptual framework (Estell et al. 2006). We tested a variety of sensors at both the SEV and JRN as part of twice yearly Jornex campaigns since 1996 (*Jornex*) (e.g., Rango et al. 2009). We continued our research on grassland-shrubland ecotones at the SEV LTER that started in 1995 with direct connections, both conceptually and experimentally, to Jornada research (e.g., Peters and Yao 2012). The small mammal exclosure study (*SMES*), now in its 16th year, being conducted at the JRN, SEV, and Mapimi, Mexico is providing information on regional variation in plant-animal interactions. We are leading the collection and synthesis of long-term data from LTER, USDA-ARS, and USFS sites through the EcoTrends Project that is resulting in synthesis publications (Moran et al. 2008, ***Peters 2010***, Bestelmeyer et al. 2011a, Peters et al. 2011b), a book to be published by the USDA (Peters et al. 2012a), and a web page for data access, analysis, and synthesis (www.ecotrends.info).

14. Sensor development. JRN researchers have made great progress in developing, using, and making accessible Unmanned Aerial Vehicle (UAV) - based remote sensing technology (Rango et al. 2009, Laliberte et al. 2011). UAV imagery has very fine resolution (5-15 cm pixel size) making it highly suitable for mapping fine-scale vegetation and soil features. Because the Jornada currently owns 3 UAVs, missions can be flown on ca. 1-2 weeks notice. Efficient workflows for image acquisition, orthorectification, mosaic-ing and vegetation classification procedures have been released to the public (***Laliberte et al. 2010***; 2011). Image mosaics provide high-resolution shrub, grass, and soil percentage cover, species composition, patch size and distribution, and shrub density. Terrain models from the imagery provide detailed digital elevation and surface models (DEM, DSM).

15. Information Management (IM). The Jornada Information Management System (JIMS) was integrated with LTER network-wide databases (ClimDB, SiteDB, Data Portal, All Site Bibliography, Personnel Directory) and websites (EcoTrends). We implemented LTER Network standards (EML, Unit Registry), and best practices and guidelines (EML, Site Review Criteria, Website Design). We also increased our in-house computational and storage capacity. The JRN website was recently migrated to an open source content management system, Drupal. We recently adopted and deployed the Drupal Ecological Information Management System (DEIMS), developed by a group of LTER sites and the University of Michigan. DEIMS powers the JRN data catalogs and populates the LTER Data Portal.

16. Supplemental funding. We received a total of \$808,107 from supplemental funding. Results from Schoolyard LTER funding (\$125,400) are described under 17. Broader Impacts. Many of our 10 REU students (\$60,000) presented posters at the annual Jornada Symposium. Supplemental awards to IM (\$165,000): (a) supported undergraduate and graduate student programmer positions, (b) replaced servers, (c) acquired additional storage capacity, sensor upgrades, and wireless enhancements to climate and hydrology stations enabling near-real time data acquisition, and (d) supported travel to production and training workshops. Supplements to our social science studies (\$41,000) supported a cross-site activity of urban development (CAP, SEV, KNZ, SGS) and the initiation of the MALS Project [Maps and Locals (MALS): A Cross-Site LTER Comparative Study of Land-Cover and Land-Use Change with Spatial Analysis and Local Ecological Knowledge] to evaluate the importance of local ecological knowledge across 11 sites. We also received support for the EcoTrends Project (\$371,000) as a collaboration with the USDA and NMSU that included 3-year salary for a project coordinator and 1-year salary for an R programmer to work with all LTER IMs and PIs to access, clean, and format key long-term datasets. We also provided local support for the EcoTrends Science and Technology Committee to meet several times a year. Key products include a book to be published by the USDA (Peters et al. 2012a) and a web site with the data and graphing/downloading tools (www.ecotrends.info). International support (\$21,250) allowed NMSU faculty to initiate collaborations in China and New Zealand. The remainder (\$24,457) initiated the cross-scale experiment and one-time sampling of imagery for plot selection (*Xscale*).

17. Broader impacts. More than 102,000 people participated in hands-on programs of the JRN schoolyard LTER (sLTER) since 1999. The majority of participants were from underserved populations from southern New Mexico and west Texas: ca. 80% are classified as "economically disadvantaged," and 75% are Hispanic. In the last six years, highlights include: (a) the program is a model used by regional school districts (El Paso Independent School District), afterschool and summer programs (e.g., Gen M summer program for middle school students), other NSF-funded programs (e.g., GK12 program at the University of Texas El Paso), and statewide initiatives (New Mexico's NSF EPSCoR), (b) sLTER staff worked with educational researchers to develop assessment tools for both formative and summative evaluation, (c) 57,256 students participated in field trips and schoolyard activities, and (d) 3,229 K-12 teachers attended sLTER programs and workshops. We also actively conducted monitoring and research activities throughout the Chihuahuan Desert and the western U.S., primarily through our collaborations with state and federal agencies, including the BLM, Natural Resource Conservation Service (NRCS), and the US Geological Survey (USGS) (Herrick et al. 2005; 2010). Our monitoring manual and qualitative assessment protocol for grasslands and savannas is in use by the BLM and NRCS. Monitoring methods are being applied nationally at over 2000 locations per year. The qualitative assessment protocol is also being applied nationally, and both protocols have been translated into Spanish, Mongolian, and Chinese.

Table 1.1. Ten most significant Jornada publications from 2006-2012

Authors	Journal citation	Impact or significance
Bestelmeyer BT, Ellison AM, Fraser WR, Gorman KB, Holbrook SJ, Laney CM, Ohman MD, Peters DPC, Pillsbury FC et al.	2011a. Analysis of abrupt transitions in ecological systems. *Ecosphere* 2: art 129	Framework for state changes that links research across diverse LTER sites.
Bestelmeyer BT, Tugel AJ, Peacock GL Jr, Robinett DG, Shaver PL, Brown JR, Herrick JE, Sanchez H, Havstad KM	2009. State-and-transition models for heterogeneous landscapes: A strategy for development and application. *Rangeland Ecology and Management* 62:1-15.	Application of ecological principles to land management
Duniway MC, Herrick JE, Monger HC	2010a. Spatial and temporal variability of plant-available water in calcium carbonate-cemented soils and consequences for arid ecosystem resilience. *Oecologia* 163:215-226	Discovered importance of petrocalic soil horizons as sources of water to plants
Havstad KM, Huenneke LF, Schlesinger WH (eds)	2006. Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin LTER. Oxford University Press	Synthesis of Jornada results from USDA (1915-06) and LTER (1982-)
Laliberte AS, Herrick JE, Rango A	2010. Acquisition, orthorectification, and object-based classification of unmanned aerial vehicle (UAV) imagery for rangeland monitoring. *Photogrammetric Engineering and Remote Sensing* 76:661-772.	Description and use of UAV for fine-scale (i.e., decimeters) image acquisition
Monger HC, Cole DR, Buck BJ, Gallegos RA	2009a. Scale and the isotopic record of C_4 plants in pedogenic carbonate: from the biome to the rhizosphere. *Ecology* 90: 1498-1511	Highlights historic shifts between C_3 shrubs and C_4 grasses
Okin GS, Parsons AJ, Wainwright J, Herrick JE, Bestelmeyer BT, Peters D	2009b. Does connectivity explain desertification? *BioScience* 59:237-244	Links multiple types of desertification by wind and water
Peters DPC	2010. Accessible ecology: synthesis of the long, deep, and broad. *Trends in Ecology and Evolution* 25: 592-601.	Framework to integrate accessible data from individuals, sites, and networks
Peters DPC, Bestelmeyer, BT, Herrick JE, Monger HC, Fredrickson EL, Havstad KM	2006. Disentangling complex landscapes: new insights to forecasting arid and semiarid system dynamics. *BioScience* 56:491-501	Conceptual framework based on interacting scales and propagating events; basis for studies in LTER-V and -VI
Peters DPC, Groffman PM, Nadelhoffer KJ, Grimm NB, Collins SL, Michener WK, Huston MA	2008. Living in an increasingly connected world: a framework for continental-scale environmental science. *Frontiers in Ecology and the Environment* 5:229-237	Framework for continental scale ecology; intro paper to special issue; instrumental in NEON design

2. PROJECT DESCRIPTION

I. Introduction

Many drylands (arid and semiarid ecosystems) of the world have experienced dramatic changes in vegetation structure and ecosystem function over the past several centuries. These changes in ecosystem state, interpreted as "desertification", are often manifested as a broad-scale conversion of perennial grasslands to dominance by xerophytic shrubs, and are often accompanied by a loss of soils and biological resources, including aboveground production and biodiversity (MEA 2005, Barger et al. 2011). Because drylands occupy 41% of the Earth's land area, state changes in these regions have important long-term and dire consequences for the provisioning of goods and services to more than a billion people who are directly linked to these landscapes (Reynolds and Stafford Smith 2002).

Current paradigms for understanding this prominent and potentially devastating state change in drylands emphasize that: (1) desertified shrub-dominated systems are difficult, if not impossible, to reverse, and persist under current environmental conditions as a result of positive feedbacks between woody plants, water, and soil nutrients (Tiedemann and Klemmedson 1973, Walker et al. 1981, Rietkerk et al. 1997, van de Koppel et al. 1997), (2) expansion of woody plants is governed by broad-scale drivers, primarily climate, fire, and livestock overgrazing, and local plant processes (e.g., grass-shrub competition) and soil properties (Geist and Lambin 2004), and (3) humans contribute to state change primarily through livestock management (Asner et al. 2004, Reynolds et al. 2007, Cowie et al. 2011).

Recent studies have challenged these paradigms by demonstrating that: (1) alternative states occur in drylands, including shifts from desertified systems back towards native grasslands or to novel systems dominated by exotic annual or perennial grasses under certain climatic and management conditions (Holmgren and Scheffer 2001, Rasmussen et al. 2001, Allington and Valone 2010, Archer 2010, Wilcox et al. 2011), (2) cross-scale interactions driving spatial and temporal variation in rates and patterns of woody plant expansion are highly complex and involve numerous feedbacks among drivers and transport vectors (wind, water, animals). The ecological responses to these interactions vary depending on spatial scale and context, and result in multiple scales of spatial heterogeneity in outcomes (Dekker et al. 2007, Ravi et al. 2007, D'Odorico et al. 2010, Turnbull et al. 2011), and (3) rapidly expanding human populations create mosaics of natural (e.g., grasslands, shrublands) and human-dominated (e.g., urban, suburban) ecosystem states that are connected at multiple scales and in multiple ways (Travis 2007, Grimm et al. 2008a; 2008b). There is a critical need to integrate these recent observations into an evolving conceptual and predictive framework for drylands. We propose to expand our landscape linkages framework (Peters et al. 2006) to fill this critical need.

The overall goal of Jornada LTER-VI (2012-2018) is to understand and quantify the mechanisms that generate alternative natural and human-dominated states in dryland ecosystems, and to predict future states and their consequences for the provisioning of ecosystem services.

The JRN LTER is uniquely poised to achieve this goal in our integrated research program that includes: (1) a history of leadership in developing theory and conceptual frameworks at the forefront of drylands science, including advances in alternative states and cross-scale interactions (Wooton 1908, Schlesinger et al. 1990, Archer 1994, Reynolds et al. 2004; 2007, Peters et al. 2004a; 2006; 2007, Bestelmeyer et al. 2009; 2011a), (2) accessible legacy data documenting trends in and constraints on drivers (climate, management history, soils), transport vectors, and ecosystem state changes from field observations, experiments, and an extensive imagery library (Buffington and Herbel 1964, Gibbens et al. 2005, Rango et al. 2011, (3) established expertise in understanding the role of connectivity by wind, water, and animals within and among spatial units (Rango et al. 2006, Peters et al. 2008, Monger et al. 2009a, Okin et al. 2009b), (4) the development of simulation models, image acquisition and analysis tools, and methods for monitoring, assessment, and prediction of state changes (Peters 2002, Herrick et al. 2005, Laliberte et al. 2010, Okin et al. 2006, Vivoni et al. 2009), (5) experience in transferring information and technology about state changes to broad audiences, including K-12 students and teachers, the general public, and private and public land managers (Herrick et al. 2010, Peters 2010, http://www.asombro.org), and (6) emerging expertise in the social and economic drivers of transitions between natural and human-dominated states, connectivity among these states at local to regional scales, and the consequences of state changes for the provisioning of ecosystem services (Havstad et al. 2007, Sala et al. 2009, Buenemann and Wright 2010, Skaggs et al. 2011, Peters et al. 2012a).

The Jornada site is broadly representative of drylands globally. Historically, the site exhibited classical grassland-to-shrubland transitions beginning in 1858 as well as less well-studied shifts between shrubland types (Gibbens et al. 2005). More recently, alternative states are emerging, including a reversal from shrublands towards perennial grasslands (Peters et al. 2012b), shifts between shrubland types, and the invasion of non-native grasses into native grasslands (McGlone and Huenneke 2004). Currently, <10% of the site is grass-dominated with shrubs as a co-dominant on many of these locations. The site typifies the climate, soils, vegetation, and livestock grazing history of the Chihuahuan Desert, its key transport vectors, and its linked natural and human-dominated systems. The American Southwest is among the most rapidly growing regions in the US. The Jornada site is situated between the rapidly expanding Las Cruces urban fringe to the south and the proposed Spaceport America to the north [the latter is a built residential and service-oriented community designed to accommodate commercial spaceflight (www.spaceportamerica.com)]. The JRN LTER is also within 80 miles of the international border and the nearly 2 million people living in the combined El Paso, TX-Juarez, Mexico area. Finally, the site is a critical node in cross-site studies within the LTER Network and the National Ecological Observatory Network (NEON) where the Jornada represents: (a) a shrubland endpoint to compare with the SEV LTER where large expanses of grasslands and grassland-shrubland ecotones still persist, (b) a desert ecotone with a small city (ca. 100,000 people) urban fringe to compare with the Central Arizona Phoenix LTER site that focuses on a very large metropolitan area in an already-urbanized desert environment, (c) a remnant subtropical desert grassland endpoint to compare with the temperate mesic grasslands at the Konza and Cedar Creek LTER sites, (d) an arid rangeland node in the emerging Long Term Agricultural Research network (LTAR), and (e) a northern Chihuahuan Desert endpoint to compare with the Sonoran Desert NEON site in southern AZ (Santa Rita Experimental Range), sites in other NEON domains (www.neoninc.org), and arid and semiarid sites globally (e.g., ILTER: www.ilternet.edu).

New research in LTER-VI will address important unresolved questions:

(1) How do we integrate diverse observations of flora, fauna, soils, hydrology, climate, and human populations within and across spatial and temporal scales to improve our ability to *understand* current and historic state changes?

(2) How do *pattern-process relationships* interact across a range of spatial and temporal scales to drive state change dynamics and regulate the conservation of ecosystem resources? More specifically, under what conditions *in time and space* do fine-scale processes propagate to govern state changes at broader spatial extents, and under what conditions do effects of broad-scale drivers constrain or overwhelm fine-scale variation in patterns and processes?

(3) How do we disentangle interactions between drivers of landscape dynamics such that we can *predict* spatial and temporal variation in state changes? How can we use knowledge of pattern-process relationships across scales to promote and prioritize the conservation of biological resources, avert undesirable state changes, and reinforce positive (desirable) state changes, including the recovery of grasslands?

(4) How do we make our data *readily accessible* in a timely fashion, our tools easily used, and our findings understood by and relevant to a broad, diverse audience?

Our integrated research plan will use extensive short- and long-term datasets and multi-scale spatial analyses to quantify a suite of natural and human-dominated state change dynamics within a framework stressing: spatial contingency and temporal context. **In our framework, spatial and temporal variation in state change dynamics are the result of:** (1) patch structure and spatial and temporal context interacting with (2) transport vectors (wind, water, animals) and (3) environmental drivers (e.g., precipitation, temperature, human activities) to (4) influence resource redistribution across a range of scales (5) as mediated or constrained by geomorphic and topoedaphic features with (6) significant effects on ecosystem goods and services (Fig. 2.1). We focus on climate and human activities as drivers of this predominantly shrub-dominated landscape with low and discontinuous grass biomass. We will strategically examine the role of fire and livestock grazing primarily through collaborations with local USDA scientists, and with the SEV LTER where grasses are still abundant. We will also collaborate with the SEV LTER on the role of fine-scale processes, including plant-microbial interactions, as mediators of ecosystem response to climate change.

Our approach will improve our mechanistic understanding of processes and our ability to integrate, predict, and extrapolate state change dynamics across spatial and temporal scales up to and including those relevant to land management and policy. **Our research will result in five major products:** (1) new understanding of state changes, in particular in drylands, that lead to theory development, testable hypotheses, and new experiments; (2) accessible data and visualization tools applicable at multiple scales; (3) explanatory and predictive relationships among drivers, patterns, and processes that can be used to (4) develop scenarios of alternative human- and natural-dominated states with assessments of their impacts on ecosystem services; and (5) usable information transfer to a broad audience (Fig. 2.2). Our approach is to test hypotheses and develop pattern-process-driver relationships using existing short- and long-term data from a suite of accessible databases as part of an iterative process in our "Data-Analysis Loop" (Fig. 2.3). New observations and experiments are then strategically designed to complement existing data. This approach requires accessible data, a top priority for our site (Peters et al. 2012). Our findings will make important contributions to ecological theory and to the development of strategies aimed at forecasting state changes (Scheffer et al. 2001, Carpenter et al. 2011). We will also build on and contribute to advances in restoration ecology, landscape ecology, ecohydrology, novel ecosystems, linked human-natural systems, and Earth system science as well as continuing our contributions to the science underpinning desertification and land management. These products are particularly timely for the United Nations Decade for Deserts and the fight against desertification (http://unddd.unccd.int/).

II. Landscape linkages: a framework for alternative states

The overall goal of the JRN LTER has remained unchanged since 1982, but the emphases have evolved through time and have led to our current landscape linkages framework. LTER-I to -III (1982-2000) focused on causes and consequences of desertification determined by processes at the plant-interspace scale (e.g., Schlesinger et al. 1990, Wainwright et al. 2002, Gillette and Pitchford 2004). LTER-IV and -V (2000-2012) considered redistribution of resources and organisms across multiple scales by focusing on patch structure and connectivity, and how these pattern-process relationships might explain spatial variation in desertification dynamics (e.g., Peters et al. 2006, Okin et al. 2009b). A conceptual framework for quantifying the redistribution of resources within and among a hierarchy of spatial scales was developed (Fig. 2.1a). We hypothesized that interactions among six key elements connect levels of the hierarchy and generate complex dynamics: (1) legacies of past climate, management practices, and natural disturbances; (2) environmental drivers, such as weather/climate and current/future disturbance regimes; (3) a soil-geomorphic template that includes both local properties (e.g., soil texture, depth, chemistry, microtopography) and geomorphology (e.g., parent material, topography) that mediate or constrain (1) and (2); (4) biotic properties and spatial arrangement of units at each scale; and (5) horizontal and vertical transport vectors that interact to drive state change by (6) redistributing resources within and between spatial units. Interactions and feedbacks among these elements propagate within, and in some cases across spatial scales, to elicit threshold changes in patch structure and associated process rates that culminate in broad-scale state transitions (Peters et al. 2004a; 2006).

In LTER-VI, we will position ourselves to transition from the heuristic conceptual phase of the landscape linkages framework to a working phase by: (a) developing approaches for representing how more detailed information on temporal (feedbacks, lags) and spatial context (contingency, adjacency) influence current states and mitigate or constrain the development of future states; and (b) including an explicit consideration of historic states (shrubland, agricultural land, perennial grasslands), and alternative future states (persistent shrublands, annual and perennial grasslands, other shrubland types, novel systems, human-dominated states [e.g., urban, suburban]) that go beyond the desertification paradigm. Complexity, contingency, lags, thresholds, feedbacks, and the interdependence of system components are major obstacles to prediction in ecosystem science. We propose to test the proposition that an explicit accounting of processes in the context of patch and geomorphic structure, temporal context, and cross-scale interactions will improve our predictive capabilities by resolving what heretofore have been seeming controversies, such as the perceived singular role of environmental drivers in state changes, and a large pool of unexplained variance (Archer and Bowman 2002, Peters et al. 2006).

Our general approach includes: (a) integration of existing short- and long-term data from different studies, (b) a suite of new and integrated cross-scale field experiments, both within the Jornada and across the Chihuahuan Desert region, and (c) forecasting alternative future landscape and ecosystem state change dynamics under a changing environment that explicitly includes socioeconomic drivers. We are integrating our fine-scale simulation model of vegetation, soil water, and nutrient dynamics (ECOTONE, Peters 2002) with wind (WEMO, Okin et al. 2006), water (Vivoni et al. 2009), and animal (Peinetti et al. 2011) transport models. The resulting multi-scale, spatially-explicit ENSEMBLE model (Ecological NetworkS Evolving in response to Multiple Biophysical Landscape Events) (Fig. 2.4) complements and guides our field studies, and enables us to explore the outcomes of complex, multi-dimensional, multi-scale interactions among system components and to predict future alternative states and dynamics. Because ENSEMBLE is modular, only the components required to address a particular question will be included in order to optimize errors of omission with errors of aggregation (Peters et al. 2004b).

III. Proposed research for LTER-VI (2012-2018)

The Jornada, located in the northern Chihuahuan Desert (Fig. 2.5a), includes the 78,000 ha Jornada Experimental Range operated by the USDA Agricultural Research Service, and the 22,000 ha Chihuahuan Desert Rangeland Research Center operated by New Mexico State University. Mean annual precipitation over the past 80 years is 24 cm; average temperatures range from 13°C in January to 36°C in June. The Jornada consists of geomorphic units defined by soils and vegetation that are characteristic of the Basin and Range Physiographic Province (Monger et al. 2006). To focus our studies and to make the problem tractable within the next 6 years, we will concentrate on the two dominant geomorphic units in the Chihuahuan Desert (Fig. 2.5b): the **basin floor sand sheet (basin)** on loamy sands dominated by perennial grasses (black grama, dropseeds) and shrubs (honey mesquite); and the **piedmont slope (bajada)** on silty and gravelly soils currently dominated by shrubs (creosotebush, tarbush) with sparse cover of perennial grasses. A hierarchy of spatial scales exists for both geomorphic units (Fig. 2.5c).

The basin and bajada have been the focus of research since the 1920s (Havstad et al. 2006). To date, each has been studied separately. However, recent analyses of species distribution maps show historic commonalities that can be used in combination with our knowledge base starting in 1915 (through the USDA) and in 1982 (via LTER) to develop testable hypotheses about drivers of alternative states, and to test specific elements of and predictions from our conceptual framework. In 1858, both the basin and the bajada were dominated by black grama grasslands with interspersed mesquite plants (Fig. 2.6a). Livestock overgrazing in the late 1800s combined with periodic drought reduced grass cover and abundance throughout the northern Chihuahuan Desert, and provided opportunities for shrub recruitment and growth. By 1915, the basin was undergoing a conversion to mesquite dominance that was nearly complete by 1998 (Fig. 2.6b,c). By contrast, the bajada in 1915 was dominated by tarbush with creosotebush an important subdominant. By 1928, creosotebush increased to dominate the upper bajada with tarbush dominating the lower bajada on shallow slopes (Fig. 2.6b,c). By 1998, the basin was dominated by mesquite, the lower bajada was dominated by tarbush, and the upper bajada was dominated by creosotebush with lower elevations containing tarbush and upper locations containing mesquite as sub-dominants (Fig. 2.6d). Although not shown at the resolution of these maps, both units have interspersed plants and patches of native (black grama, dropseeds, bush muhly) and exotic perennial grasses (Lehmann's lovegrass) that have increased locally since 2004, coincident with a sequence of wet years.

Some of these observations are consistent with our knowledge base: patterns of mesquite expansion driven on the basin are well-documented (e.g., Okin and Gillette 2001, Browning et al. 2011), and the importance of interactions among aeolian processes, mesquite plants, and bare soil gaps in driving these dynamics has been the focus of a number of our studies (Gillette and Monger 2006, Okin et al. 2006, Li et al. 2008). Similarly, the role of soils and hydrologic connectivity in maintaining tarbush on the lower bajada and creosotebush on the upper bajada has been investigated for decades (Wieranga et al. 1987, Wondzell et al. 1996, Rango et al. 2006, Weems and Monger 2012). **We cannot, however, account for five critical dynamics that occur in drylands worldwide, and challenge our understanding of these systems. These challenges lead to critical knowledge gaps that will be addressed in LTER-VI.** 1: Grassland to shrubland transitions: the transition from black grama grasslands with scattered mesquite in 1858 to three spatially-distinct shrub-dominated states by 1998 suggests an incomplete understanding of desertification dynamics. The processes leading to the different dynamics on distinct geomorphic units are unknown. 2: Shrubland to grassland transitions: the recent increase in native perennial grasses in some desertified shrublands suggests that climate variability (e.g., the sequencing of wet years) can initiate state change reversals, but the processes and climatic events promoting the long-term persistence of grasses are unknown. Grasslands and shrublands have oscillated in dominance in this region throughout the Holocene (Van Devender 1995) and projections of increased summer rainfall (Woodhouse et al. 2010) may portend another climate-driven state change. 3: Shrubland to shrubland transitions: transitions between shrubland types suggest that shrub-dominated states are dynamic in the post-enchroachment phase. It is unknown if drought-avoiding mesquite will give way to creosotebush, a true xerophyte, on the sandy basin under future climatic conditions. 4: Transitions to novel states: recent increases in non-native grasses suggest that the future of the Chihuahuan Desert may include new species assemblages and novel ecosystems (Ryan et al. 2008). A fifth dynamic is represented by shifts between natural and human-dominated states that is occurring at an unprecedented rate throughout the American Southwest.

Our research activities are organized into three major sections to allow us to address these recently identified knowledge gaps by investigating key properties of arid ecosystems, and testing hypotheses about these five classes of dynamics. Core long-term studies (addressed in Section IV) have been re-evaluated. Some will be maintained, others will be continued with restructuring aimed at freeing up resources for other activities, and others will be expanded and integrated with other studies to experimentally evaluate key elements of our conceptual framework. A suite of new studies (described in Section V) will integrate existing short- and long-term core data with strategic collection of new measurements or new manipulations. These studies are designed to investigate: how changes in patch structure influence the effects of transport vectors and drivers on resource redistribution and connectivity across scales to attenuate or amplify ecological state changes; the role of spatial and temporal context in mediating change; and the nature of changes that propagate across scales to culminate in state transitions. Alternative futures and consequences for ecosystem services (described in Section VI) will integrate ecological, social, and economic systems.

IV. Existing core long-term studies and sensor network

Core long-term studies and distributed sensors provide: the context for short-term and new efforts; data to separate trends from natural variability; insights needed to design new experiments; and comparative data for the LTER network, other research sites nationally and globally, and emerging networks such as NEON and the LTAR (Fig. 2.7). Details of each study are shown in Suppl. Table A1, and core long-term study names are shown in italics in Section V. Spatial and temporal variation in environmental drivers and transport vectors will continue to be monitored via our sensor network. The number, type, and wireless connectivity of sensors will be increased as funding permits. Two priorities are the expansion of our air temperature network to capture spatial variation in extreme temperature events (e.g., unusual freeze in 2011) and an increase in the frequency and density of soil water measurements. We also continue to recover historic information, and to add it to our digital map library (http://jornada-www.nmsu.edu/galleries/mapgallery.php). The online static maps consist of elevation, hydrology, soils, management practices, and vegetation, and our interactive map link includes weather, infrastructure (pastures, roads, fences, etc.), and study locations (http://jornada-vgis.nmsu.edu:8399/JornadaMap). We have an extensive imagery library dating to the 1930s. We continue to work with State archeologists to document the location of prehistoric Jornada Mogollon encampments. These maps will allow us to ascertain the potential importance of historical legacies to dynamics of present-day ecosystems.

V. New integrated studies

A suite of new studies builds on and integrates existing long-term data to elucidate how feedbacks among fine-scale changes in patch structure, transport vectors, and environmental drivers interact to generate the classes of state changes described in Section III. We will focus on the role of four determinants of whether or not small, discrete events propagate to larger areas: (1) the role of soil properties and landscape position within geomorphic units in mediating change, (2) how changes in patch structure interact with transport vectors and environmental drivers to affect resource distribution, (3) the degree to which changes in patch structure overwhelm within-patch processes (e.g., competition), and (4) how spatial and temporal context govern variation in these dynamics. These determinants will be examined in the context of known historic legacies and environmental drivers (Fig. 2.1a). We hypothesize that changes in patch structure will modify the effects of transport vectors and environmental drivers on resource redistribution and consequent feedbacks to patch structure. Transport vectors with the largest expected effects on resource redistribution are broad-scale physical vectors (wind, water). We will investigate effects of changes in patch structure at different spatial scales and with respect to transport processes occurring over different spatial extents. The characteristic scales and dominant patch-resource redistribution interactions differ among geomorphic units, and result in differing scales of patchiness and redistribution among units. Below we describe our proposed studies and indicate the PIs responsible for the research. These studies will investigate: (a) state change dynamics within geomorphic units (Objs. 1-4), (b) the comparison of state change dynamics between geomorphic units (Obj. 5), and (c) linkages between the Jornada and human-dominated states throughout the northern Chihuahuan Desert region (Obj. 6). Details of each core long-term study and associated datasets are shown in Suppl. Table A1 along with the Objectives where the data will be used. Data from short-term studies will also be used in our integrative approach that are not included below due to space limitations. Cross-site comparisons within each objective will enable us to both test the generality of our findings and to place Jornada results within a broader context.

TRANSITIONS WITHIN GEOMORPHIC UNITS

Obj. 1. Grassland → shrubland transitions *(Okin and B. Bestelmeyer [co-leads], Duniway, Archer, Throop)*. The global grassland-to-shrubland conversion has led to a search for generalizations in causal drivers (Scholes and Archer 1997). Broad-scale drivers, including drought and livestock overgrazing, have played a role in many locations, but clear, conclusive cause-effect relationships are elusive (Archer et al. 1995, Reynolds and Stafford Smith 2002). Multiple drivers interacting across scales combine with positive feedbacks to lead to a self-perpetuating process (Geist and Lambin 2004, Turnbull et al. 2011, D'Odorico et al. 2012). Conceptually, transitions can be viewed as the outcome of shifts in feedback processes operating against a backdrop of external drivers (slow variables, discrete triggers) that cause systems to reorganize around an alternative attractor (i.e., thresholds; Suding and Hobbs 2009). The 'driver-feedback-threshold' theory for desertification has focused on feedbacks between grass patches and soil water (Reitkerk et al. 2002, Kéfi et al. 2007, Scheffer et al. 2009, D'Odorico et al. 2010). A complementary approach focuses on later stages of desertification when bare soil interspaces (i.e., gaps) between shrubs are prominent. Past JRN research has focused on the creation of fertile islands under shrubs that result from wind and water deposition of resources facilitated by increased gap connectivity (e.g., Schlesinger et al. 1990, Reynolds et al. 1999). More recent research indicates that a change in the distribution of bare gaps is critical to the propagation of plant-scale dynamics to landscape-scale state changes (Peters et al. 2004a; 2006, Okin et al. 2009a), including those on downwind locations not experiencing changes in external drivers (Okin et al. 2006). These two perspectives (grass patch, bare soil gap) have largely developed in parallel. There is a critical need to integrate them to understand the full suite of pattern-process relationships involved in grassland-to-shrubland state changes. We will test the following hypothesis:

Hypothesis 1: As connectivity in bare patches at the dominant scale of resource redistribution increases, the rate and magnitude of material transfer via wind and water increases. A threshold level of connectivity is reached wherein the spatial extent of shrub dominance increases nonlinearly. Ensuing positive feedbacks reinforce bare ground connectivity and shrub dominance to escalate resource loss across increasing scales. Inter-annual variation in precipitation mediates bare gap connectivity and shrub recruitment (i.e., increases in dry years and decreases in wet years).

Three inter-related studies will test specific elements of this hypothesis. We will focus on black grama – mesquite shrubland transitions on the basin floor, taking advantage of existing experimental infrastructure and long-term data. <u>First</u>, we will determine how decreases in grass patch size affect microclimate, grass tiller/plant stress and persistence, and associated ecohydrological and herbivore-mediated feedbacks. Monitoring studies indicating threshold dynamics associated with reductions in black grama cover and patch fragmentation will be complemented with mechanistic tests of the underlying causes of these threshold behaviors. <u>Second</u>, we will examine how grass patch fragmentation influences soil redistribution, shrub expansion, and loss of grasses in later stages of grass-to-shrub transitions. Recent results show aeolian transport and nitrogen losses are associated with grass cover thresholds (Li et al. 2007; 2008), but the consequences for shrub propagation and further grass loss are unknown. <u>Third,</u> we will initiate a shrub expansion-grass loss event by experimentally elevating soil and nutrient transport, and measuring downwind effects on shrub recruitment and grass loss. Long-term experiments will quantify the multiple stages of shrub expansion and grass loss through time as precipitation varies. USDA collaborators will examine effects of fire and livestock grazing on these transitions for a subset of experimental locations.

Hypothesis 1 (a) As grass patches become smaller and more fragmented, grass resilience decreases such that plants and tillers within small grass patches will have lower fitness and greater water stress than those in large patches. Bare gap connectivity and the rate/magnitude of material transfer via wind/water will increase to further increase grass fragmentation.
This hypothesis will be tested using measurements within the 18 units of the *MSE* initiated in 1995 with a one-time pulse of heavy cattle grazing pressure designed to cause a major reduction in black grama cover. Observations suggest that low cover persists to the present that have not been quantified. We propose to quantify microclimate, plant stress, and biomass for bare gaps, for interiors of large patches, and for a range of grass patch size classes (36 of each): small (≤ 20 cm-diam.), medium (20-60 cm-diam.), and large (> 60 cm-diam.). Half of the plots will exclude rodents to examine effects of granivory and herbivory on plant responses. Measurements will include (a) seedling and ramet recruitment, and growth on focal black grama plants; (b) seasonal, diurnal net photosynthesis, and stomatal conductance (LI-6400) and leaf water potential (pressure chamber); and (c) seasonal soil water content (5-10 cm depth) in bare gaps [10HS sensors, Decagon Devices linked to a multiplexer and data logger (AM16/32B, CR1000, Campbell Scientific)]. Soil water measurements will be triggered by rain events to obtain dry-down curves. Relationships between plant metrics, soil water, and patch size will be analyzed using generalized linear mixed-effects models.

Hypothesis 1(b) As bare gap sizes increase, a connectivity threshold level is reached that sets the stage for nonlinear increases in the spatial extent of shrub dominance owing to negative effects on grass persistence [1(a)] and positive feedbacks to shrub establishment and growth.
This hypothesis will be tested on plots established in 2004 in the *NEAT* where 0, 50, 75, or 100% of original herbaceous cover was removed (and maintained thereafter) from 25 x 50 m plots in each of three blocks (Li et al. 2007). These removals generated varying levels of grass fragmentation with consequent effects on shrub expansion and grass loss in contiguous downwind plots that have been qualitatively observed (Alvarez et al. 2012). We propose to quantify (a) downwind effects at different fetch lengths, (b) vegetation feedbacks on gap size and aeolian transport, and (c) effects of interactions between climate and dust flux on plant mortality through time. We will continue to monitor aeolian sediment flux, vegetation composition (line-point intercept and gap-size distribution; Herrick et al. 2005), individual plants (*sensu* Alvarez et al. 2011), and soil C and N (*sensu* Li et al. 2008) and will relate dynamics in these variables to precipitation. Results will be analyzed by ANCOVA with flux, bare gap size, or herbaceous cover as continuous variables. We will also use the wind and vegetation dynamics components of our ENSEMBLE model to identify threshold effects of grass cover on connectivity by wind for different amounts of precipitation, and to determine feedbacks to shrub establishment and growth via changes in the deposition or erosion of soil and nutrients.

Hypothesis 1(c) Vegetation and resource losses propagate to initiate state change dynamics in downwind /downslope locations.
This hypothesis will be tested in a new long-term experiment, the *Dune Development Study (DDS*), where vegetation will be removed annually from a 100 m x 100 m plot in a grass-shrub location with soils similar to the *NEAT* plots. This new study builds on the *SCRAPE Study* where all vegetation was removed from half of a 100-diam circle in 1996, but only on-site soil properties were measured (Gillette and Pitchford 2004); unexpected and dramatic effects on downwind vegetation were observed but not quantified. In addition, soil movement transects established in the 1970s (*SoilMove*) provide historic context of changes in soil height with shrub invasion. In the *DDS*, grass, shrub, and bare patch sizes and spatial locations will be quantified pretreatment, and annually at the end of each growing season in a centered, contiguous 50 x 50 m plot downwind and in an upwind control plot of the same area. Soil erosion and deposition will be measured using erosion bridges and aeolian samplers (BSNEs). Vegetation and gap size will be quantified annually on ten 50-m transects perpendicular to the prevailing wind. Individual grass patches and shrubs will be marked and measured to identify seedling establishment, growth, contraction, and mortality. Nadir-looking digital photographs (four dates/year; 10-m intervals) will quantify the distribution, mass, and spatial pattern of surface litter in relation to vegetation; and litter samples will be collected for C/N analyses. Estimates of soil stability and threshold wind (shear) speed for transport will be mapped to determine relationships among type of plant and litter cover, soil stability, and aeolian threshold. Litter detachment and transport will be quantified using labeled or artificial litter. Litterbags will be used to quantify soil-litter mixing and decomposition (*sensu* Throop and Archer 2007) where litter does and does not accumulate. Repeat imagery using our UAV (Unmanned Aerial Vehicle; Rango et al. 2009) will allow patch-scale monitoring of individual grasses and shrubs, and surface litter cover through time as precipitation varies. We will use the ENSEMBLE model to predict rates of dune formation and loss of grasses with distance from the treatment plot as precipitation varies through time.
Cross-site analyses: Measurements of gap size distribution have been adopted by US federal agencies and resulting data will be analyzed (e.g., Herrick et al. 2010). The relationships between multi-scale patterns and processes, and concepts for ecological states are being addressed by JRN PIs working in Mongolia, China, and Argentina that will allow global-level syntheses within the next several years.

Obj. 2. Shrubland → grassland transitions *(Peters and Sala[co-leads], Duniway, Okin, Vivoni).*
Shrubland-to-grassland transitions have occurred several times during the Holocene in the American Southwest due to broad-scale climate change (Van Devender 1995, Monger et al. 2009a). Current shrub species are considered to be native given their presence over this long time period. The most

recent shift from grasslands to shrublands occurred at a much faster rate (100-150 years) than previously as an unintended result of land management practices acting in concert with periodic drought (Humphrey 1958). These shrublands are typically stable even if the primary driver of expansion is removed (Archer 1989). Management aimed at restoring shrub-encroached grasslands has met with limited success (Herrick et al. 2006, Archer et al. 2011). Restoration of grasses following desertification is one of the major challenges facing humanity today (Arnalds and Archer 2000, Reynolds et al. 2007, http://www.unccd.int/). Recent observations suggest that grasses can recover under some conditions (e.g., following a sequence of wet years; Peters et al. 2012). In contrast to many studies (e.g., Lauenroth and Sala 1992, Knapp et al. 1998, Huxman et al. 2004), grass production (ANPP) in shrublands was not related to precipitation (PPT) during this wet period, but increased nonlinearly as the number of wet years increased. ANPP was maintained in subsequent dry (2009) and average years (2010), ostensibly reflecting accumulations of biomass and litter that increased fine-scale water availability (Peters et al. submitted). Results from rainfall manipulation experiments suggest that dominant C_4 grasses have greater physiological responses to increased summer rainfall compared with C_3 shrubs (i.e., mesquite) (Throop et al. 2012). A recent integration of multiple long-term datasets suggests that a sequence of events occurred, from grass seed production and establishment at the plant-scale (2004-06) to the development of positive plant-soil water feedbacks at the patch-scale (2006-08) (Fig. 2.3; Peters et al. submitted). Finally, there are time lags in responses to changes in PPT that result from biotic legacies of dry years (causing less production than expected based on current-year PPT) and legacies of wet years that enhance production (Reichmann et al. 2011). It is unknown if these plant-soil water feedbacks with time lags occur in temperate grasslands (e.g., Briggs et al. 2005) or are unique to drylands.

Mechanistic responses to prolonged changes in water availability have rarely been explored in grasslands and shrublands; most manipulations have either been short-term or focused on drought (e.g., Reynolds et al. 1999, Evans et al. 2011). Depending on location, global climate models predict either a directional increase or decrease in PPT in arid regions with global warming (Burke et al. 2006, IPCC 2007, Seager et al. 2007). A drier climate is expected to promote continued shrub dominance and expansion (Objective 1) whereas increases in PPT are predicted to promote grass expansion and a reversal of shrub dominance (Peters et al. 2012b). Annual PPT has increased in some regions over the past 50 y (Karl and Wright 1998), justifying the need to understand the mechanisms involved in grass recovery and leading to the question: what processes might stabilize existing grasslands and reverse shrub encroachment that has been occurring over the past 150 y?

Hypothesis 2. Directional increases in water availability that favor grasses over shrubs across a range of scales are reinforced through time as grasses increase in cover and abundance.

We propose to test three related hypotheses in two experiments combined with simulation modeling analyses and a regional analysis of multiple long-term data sets. Our experiments will focus on mesquite-black grama transitions to complement studies in Objective 1.

Hypothesis 2 (a) Immediate responses to changes in precipitation are mediated by physiological changes at the plant-scale, followed by longer-term changes in demography at the plot scale, and in species dominance at the landscape scale.

This hypothesis will be tested by continuing a plant-scale, long-term water manipulation experiment initiated in 2006 *(CCE).* Treatments include reduction (-80%), ambient control, and supplementation (+80%) for 2 m x 2m plots centered on individual mesquite shrubs of similar size with similar grass cover. Plots are located in three blocks to examine spatial variability at the plot to landscape scale. Although our focus here is on long-term increases in rainfall, drought plots (-80%) will be maintained to enable comparisons of grass and shrub responses to potential precipitation scenarios and to provide additional information to test Hypothesis 1. We will continue measuring (a) climatic variables (e.g., PPT, temperature), (b) soil-water content continuously (0-30 cm depth), (c) physiological responses of black grama and mesquite plants following selected PPT events, (d) measuring demographic responses of all species (seedling recruitment, tiller and plant density, meristem density), and (e) species ANPP and cover. We will also use our vegetation dynamics model linked with a daily timestep soil water model (Ecotone; Peters 2002) as part of our ENSEMBLE model to examine species and ecosystem responses to additional rainfall regimes, such as altered seasonality (winter vs spring vs summer) and distribution of rain events (large vs small) that are difficult to examine experimentally. *Cross-site analyses:* This shelter design is used in experiments from Alaska to Patagonia (Yahdjian and Sala 2002; Yahdjian et al. 2006; Santa Rita NEON, AZ; SEV LTER, NM; SGS NEON, CO; Arctic LTER, AK). Cross-site syntheses will explore scenarios across diverse bioclimatic zones as data become available, and will be facilitated by a future Research Coordination Network proposal to NSF.

Hypothesis 2 (b) As grass plant and patch density, size, and cover increase, connectivity in bare gaps, wind and water erosion rates, and amounts of material transfer decrease. A threshold level of connectivity in grass patches is reached wherein plant-scale biotic processes overwhelm patch-scale physical processes of erosion and deposition by wind and water. Beyond this threshold, grass recovery is initiated or maintained via positive feedbacks that propagate over larger areas. This hypothesis will be tested by integrating experimental results from a new cross-scale study of plant and patch scale processes in our ENSEMBLE model. In LTER-V, we used a pilot study to show that small artificial wire mesh structures (ConMods) can effectively modify the dominant driver of resource redistribution (water or wind) to generate fine-scale patterns in grass recovery (*ConMod)*. Preliminary data show that ConMods accumulate litter, seeds, and soil, modify the microclimate, and stabilize the soil surface sufficiently to allow plant establishment and initiate plant-soil feedbacks (Peters et al. 2012b). Field observations suggest that litter accumulation has consequences for plant demographic processes (Peters et al. submitted). These patch-scale patterns are expected to propagate through time and space to promote grass dominance at the landscape scale with implications for regional scale, land-atmosphere interactions. We recently initiated a new long-term experiment (*Xscale*) based on patterns in our long-term data (Fig. 2.3) to link pattern-process interactions across scales, and to address two questions: (a) At what spatial scales and under what weather conditions do fine-scale processes propagate to produce broad-scale impacts that lead to grass recovery? (b) At what spatial scales do broad-scale drivers (drought or extended wet periods) overwhelm or interact with fine-scale processes? Large plots (>100 m2) needed for redistribution of resources among patches are not logistically feasible for experimental water additions in this environment (K. Havstad pers. comm.). Thus, we are focusing on modifying fine-scale water availability, and monitoring responses through time under natural rainfall. Plant-scale manipulations will be achieved by eradicating individual mesquite, and using ConMods to reduce bare gap size below 1 m-diameter to minimize erosional losses at the patch-scale. Plots were located in 2011across a gradient of grass and shrub cover to examine effects of initial conditions, and to identify thresholds in grass cover and bare gap size where the dominant process shifts from the plant to patch scale. The LTER is setting up and maintaining the 60 10 m x 15 m plots, characterizing the broad-scale drivers, and conducting long-term vegetation sampling. We are collaborating with the USDA to fund a postdoctoral research associate to lead this field effort, and to install water, wind, and energy balance sensors in a subset of plots that will be expanded as funds are available. As grass cover and biomass increase, our USDA collaborators will examine effects of fire and livestock grazing on these transitions for a subset of experimental locations. We will use our ENSEMBLE model to investigate threshold dynamics and feedbacks across scales, and to predict alternative states under climate change. *Cross-site comparisons:* This cross-scale approach is expected to provide new insight into numerous failed attempts to restore perennial grasslands that focused on individual scales (Herrick et al. 2006), and will apply to state change dynamics in other ecosystems. For example, USGS and National Park Service collaborators recently expressed interest in cross-site comparisons of the effects of ConMods in modifying connectivity across the Colorado Plateau.

Hypothesis 2 (c) The importance of multiple wet years in explaining variability in ANPP decreases with increases in mean annual precipitation.

Time series ANPP and PPT data from 24 grassland and shrubland sites in North America will be obtained from EcoTrends (http://www.ecotrends.info) a standardized long-term ecological database. Effects of PPT in the two and three previous years on ANPP will be assessed for multiple locations within each site where data are available. This approach has the advantage of a well-replicated design with a broad and detailed spatial scale, and a long time series encompassing a broad range of PPT variability. The broad range encompassed in the independent variables tends to increase the coefficient of determination of the regression analysis and allows comparisons of results with other analyses with a similar range in PPT (Kutner et al. 2005).

Obj. 3. Shrubland → shrubland transitions *(Vivoni and Archer [co-leads], Monger, Peters, Tweedie; Collaborator: Browning [USDA]).* Topoedaphic factors are thought to control the distribution and abundance of major shrub species (mesquite, creosotebush, tarbush) throughout the Chihuahuan Desert (Hallmark and Allen 1975, Mabry et al. 1977, Simpson 1977, Grover and Musick 1990). However, Jornada vegetation maps circa 1858 show these shrub communities and the states they represent have been dynamic (see Section III), and their distributions are not entirely controlled by soils (Gibbens et al. 2005). Here we develop testable hypotheses proposed to account for three observed patterns: (a) the increase in mesquite to dominance on the basin, but not the bajada, despite being present on both in 1858, (b) the shift on the upper bajada from a grassland in 1858 to a tarbush state by 1915 followed by a shift to a creosotebush state by 1928, and (c) the current dominance of a creosotebush state on the upper bajada, a tarbush state on the lower bajada, and a mesquite state on the basin. Because all three species are long-lived (decades to centuries), we will focus on seedling establishment as a key process explaining the initial shift from grasslands to shrub-dominated states, and we focus on competition and phenology to explain state changes between shrubs.

Establishment. We predict that the increase in mesquite in the basin, and increase in tarbush with little change in abundance of mesquite through time on the bajada are related to topoedaphic influences on shrub seedling establishment. Sandy soils on the basin with high rates of infiltration, and deep depths to calcium carbonate ($CaCO_3$) layers that impede infiltration should favor establishment of mesquite seedlings that allocate substantial biomass to early tap root development (Brown and Archer 1990). By contrast, loamy soils with shallow depths to $CaCO_3$ layers on slopes of the bajada have higher water availability near the surface, lower rates of evaporation and infiltration, and increased runoff compared with sandy soils. These conditions should favor shrubs investing more biomass in lateral roots (creosotebush) than tap roots (tarbush). Further, because tarbush initially increased to dominance on the bajada between 1858 and 1915, we predict that seedlings of tarbush utilize shallow water that inhibits establishment of creosotebush seedlings (Musick 1978, McGee and Marshall 1993, Woods et al. 2011). These patterns lead to our first hypothesis:

Hypothesis 3 (a). Mesquite seedlings require water at deeper depths compared with tarbush seedlings that require reliable water only in surface soils; creosotebush seedlings also have low demands for water in surface and deeper soils, but are inhibited by ephemeral high soil water contents that promote mesquite and tarbush establishment.

Because little is known about seedling establishment requirements for these shrubs, we will first conduct model simulations to identify the combination of conditions (climate, soils, topography) that generate their current patterns in abundance. We will use the daily time step, multi-layer SOILWAT model (modified from Parton 1978), the vertical water redistribution model in ENSEMBLE, with our vegetation, soil, and elevation maps, climate data, and a series of biotic parameters defining the amount and timing of water inputs needed (by depth) for successful seedling establishment in a given year as input to the model (*sensu* Peters 2000). Seedling establishment will be the output (Peters et al. 2010). Uncertainty analyses will be used to examine how variation in biotic parameters affects patterns in establishment as compared with species dominance through time. The importance of changes in soil surface texture, and in particular, the loss of silts and clays from the upper to the lower bajada, on simulated establishment will be examined, and changes in the surface (0-20 cm) silt and clay content will be verified using soilstratigraphic techniques (i.e., mapping erosional areas based on gully formation and truncation of soil horizons, laterally tracing buried land surfaces in depositional areas, radiocarbon dating, and $\delta\,^{13}C$; Weems and Monger 2012). We will also determine how soil carbon in uneroded soil profiles has changed through time, especially inorganic carbon (i.e., calcium carbonate), for which there is little information. These simulations will provide boundary conditions on the soil water conditions required for the germination and establishment of creosotebush, mesquite, and tarbush seedlings. Second, we will use SOILWAT to examine the sensitivity of recruitment by each species to changes in herbaceous cover, surface and deep soil properties, and topography; and to predict future patterns in recruitment under alternative climate change scenarios that include both drier and wetter seasons (e.g., wetter/drier winters vs wetter /drier summers), and sequences of years (drought, wetter periods) that are important to grass recruitment (Obj. 2). *Cross-site analyses:* These analyses are similar to previous simulations of dominant grasses at the Shortgrass Streppe (SGS and SEV LTER sites (Lauenroth et al. 1994, Minnick and Coffin 1999, Peters 2002). After calibrating the model for shrubs at the Jornada, we will repeat the simulations for the northern Chihuahuan Desert, including the SEV LTER, where long-term climate data and maps of soils and topography exist (e.g., Rastetter et al. 2003). We will ask if the regional distribution of each species is limited by soil water availability by depth, and will determine through a sensitivity analysis which factors (soils, topography, climate) have greater importance to regional patterns in establishment.

<u>Competition and phenology.</u> Shifts between alternative shrub states are likely related to plant functional trait-environment interactions (Ho et al. 1996, Reynolds et al. 1999). Phenological variables related to leaf longevity (e.g., green-up, leaf area duration, senescence, detachment) are predicted to be the most important functional trait differences among the three species: creosotebush (evergreen), mesquite (winter deciduous, N_2 fixer), tarbush (summer deciduous). We therefore predict that these species will respond differentially to changes in the vertical and horizontal redistribution of seasonal soil water. Canopy and root characteristics effects on productivity have been quantified (Ivanov et al. 2008). Here, we focus on how contrasting shrub phenologies are influenced by, and in turn influence, soil water with impacts on and feedbacks to hydrologic lateral connectivity (LC), shrub growth, and soil water. The impact of phenology on watershed-scale soil moisture and runoff responses, and how these interact with rainfall and topographic position to induce hydrological connectivity, is not well known (Vivoni 2011). Water used by plants is not available for hydrologic LC. Interactions with abiotic factors (rainfall intensity, slope, soil depth) lead to thresholds above which differences in phenology are overwhelmed by physical drivers. LC mediates plant-patch dynamics in the upper and lower bajada that affect shrub transitions. Creosotebush dominates portions of the landscape where runoff losses are high whereas tarbush predominates on depositional areas with sandy or silt soils. Thus, plant-patch dynamics interact with properties of a geomorphic unit through variations in LC. We predict that these factors will explain the observed historical shifts in shrub dominance on the upper and lower bajada. Existing instrumentation will be used to quantify plant phenology, and to address the following hypothesis:

Hypothesis 3 (b). Differences in phenology among mesquite, tarbush, and creosotebush relative to the seasonal timing of plant available water by depth governed historic shifts in shrub-dominated states, and determined current dominance patterns on the bajada.

This hypothesis will be tested by combining long-term and on-going observations, historical and UAV imagery, phenological measurements, and numerical experiments using the tRIBS model, the horizontal water transport model in ENSEMBLE (Vivoni et al. 2007, 2010; Ivanov et al. 2008). Two shrub sites with extensive sensor networks will be used: (1) Tromble Weir (*TW*) watershed and (2) Creosotebush eddy covariance (*CEC*). Each site encompasses a phenological study (*PHENOMET*; Dr. Dawn Browning, USDA) that builds on our long-term monthly observations of phenology (*Phenology*). *PHENOMET* has an increased sampling intensity (more species and individuals) and frequency (from monthly to weekly) with a goal to relate phenological patterns of key grass and shrub species to precipitation, temperature, and soil moisture. These relationships will be used as input to the tRIBS model. Long-term ANPP, biomass, and rainfall relations from similar shrublands will be incorporated (*NPP)* (Peters et al. 2012b).

Long-term rainfall and runoff data are also available at *TW* (Moran et al. 2008). UAV images (monthly) and species classifications will be verified with *PHENOMET* data. By linking imagery to historical rainfall, we will derive synthetic, long-term phenological fields that will be compared to historical photography to expand the spatial extent. We will parameterize tRIBS for tarbush, creosotebush, and mesquite dominated landscapes using prior studies (e.g. Abrahams et al. 2003; Kurc and Small 2004). tRIBS has been used at the SEV LTER (Ivanov et al. 2008), at *TW* in LTER-V (Templeton et al. 2010), and is being applied at the Santa Rita NEON site in Arizona (Pierini et al. 2011). Here, we will simulate the *TW* site by assuming different shrub dominance (1858: black grama-mesquite; 1915: tarbush; 1928: creosotebush; 1998: creosotebush-mesquite), and ask how LC is affected by phenology and other plant/soil properties, with consequences for dominance. We will conduct simulations at two scales: (1) single plant-patch sites at *CEC* and *TW*, and (2) the entire TW (~5 ha). We will compare phenological scenarios obtained from: (a) UAV imagery of actual conditions (model calibration), and (b) synthetic fields derived from UAV imagery and relation to historical records (model scenarios). We will use the model at *CEC* and *TW* to test the impact of shrub phenology on LC relative to other plant properties; to identify thresholds related to abiotic properties; and to identify how LC has consequences to future shrubland states. These results will also be compared with the importance of LC by wind to shrubs (Obj. 1) and grasses (Obj. 2) for a more synthetic understanding across geomorphic units. *Network collaborations*: Our ecohydrology studies complement efforts at the SEV LTER (Gutierrez-Jurado et al. 2010), Santa Rita NEON (Pierini et al. 2011), and Sonora, Mexico (Vivoni et al. 2010). We collaborate closely with the National Phenology Network (NPN) to jointly develop and implement standardized protocols for phenology in arid and semiarid systems. This effort will result in cross-site comparisons across the country as additional sites join the NPN. We will also take advantage of broad-scale plant-soil inventory data gathered for the Chihuahuan Desert region (Bestelmeyer et al. 2009) to test for associations between shrub species dominance and soil properties outside of the Jornada.

Obj. 4. Shrublands or grasslands → novel states *(Peters, Archer).* Substantial portions of the Great Basin and Sonoran Deserts have been invaded by non-native grasses to result in altered hydrological and fire regimes that promote further invasion (Ravi et al. 2008, Wilcox et al. 2011) with resultant losses in biodiversity. For reasons unknown, the northern Chihuahuan Desert has been resistant to these invasions. However, recent large increases in Lehmann's lovegrass in black grama grasslands on an upper bajada location at the Jornada during the wet years of 2004-2008, and increases by the same species in a basin location following controlled burns have raised concerns about the vulnerability of these systems in the future as temperature increases (McGlone and Huenneke 2004, Archer and Predick 2008, Peters et al. 2012b). **Hypothesis 4. Increases in temperature will favor establishment of exotic grass seedlings, and increases in spring precipitation will accentuate rates of expansion.** We will repeat mapping efforts of the Lehmann's lovegrass spatial extent in both locations on the JRN, and will collaborate through Peters on a recently funded NSF Macrosystems project (EF-1065699) to investigate the temperature and soil water conditions that allow widespread invasion by these grasses and how these invasive grasses might inhibit shrub establishment (Obj. 3) (e.g., Mau-Crimmins et al. 2006, Schussman et al. 2006). *Regional analyses:* We will work with a postdoc on the Macrosystems project to conduct simulations of exotic grass invasion for the JRN and throughout the American Southwest under alternative climate scenarios. Regional consequences of novel states will be investigated through linkages with meso-scale land-atmosphere models.

COMPARISONS OF TRANSITIONS BETWEEN GEOMORPHIC UNITS

Obj. 5 (a) Hydrologic lateral connectivity *(Vivoni, Rango; Collaborator: Fernald [NMSU]).* Hydrologic transports connect geomorphic units across topographic gradients, and affect current vegetation and soils (Wondzell et al. 1996). The importance of hydrologic LC for state change depends on the degree of connectivity (Bestelmeyer et al. 2011b). For landscapes with similar vegetation and slope, we predict that connectivity will be determined by soil properties in upslope locations (via infiltration and runoff) or by the availability of additional water sources (e.g., groundwater) that overwhelm water run-on. **We hypothesize that: (a) state changes in uplands with gravelly soils and high infiltration will have low runoff with little or no effect on vegetation on downslope locations. By contrast, state changes in uplands with deep, silty soils with low infiltration and high rates of runoff will markedly influence vegetation dynamics downslope, and (b) downslope areas with groundwater sources are hydrologically disconnected from state changes in upland locations.** We will quantify LC between two types of uplands (relict alluvial fans on gravelly soils, inter-fan valleys on deep, silty soils) with downslope locations, and along a gradient from uplands to downslope locations with groundwater. We will combine long-term field observations, historical and UAV imagery, and numerical experiments at: (1) the instrumented Tromble Weir site (*TW*), (2) instrumented (n=4) and ungauged stock ponds *(PONDS),* and (3) a location along the upland-river valley (Rio Grande) transition (Sam Fernald, NMSU). Upstream watersheds for each pond (n=77) will be characterized with terrain data (1-m) from UAV imagery and our geomorphology map (Monger 2006) to identify relict fans and inter-fan locations (Templeton et al. 2010). Additional ponds will be instrumented to cover spatial variability. A similar approach will be used at the upland-to-river site. Rainfall-runoff relations will be derived for each pond using long-term PPT data and our vegetation maps (*VegMaps*) (Gibbens et al. 2005). Historical reconstructions will be compared to current vegetation. The tRIBS model will be used to estimate flows linked to vegetation state changes. Model calibration will be conducted at *TW* and verified at *PONDS.*

Obj. 5 (b) Patterns in soils and geomorphology *(Monger, Duniway)*. Although the soil-geomorphic template is an important feature of drylands that interacts with environmental drivers to influence state change dynamics (Monger and Bestelmeyer 2006), we do not have an accurate, fine-scale map of soil properties for the entire Jornada. This map is needed to test hypotheses about these interactions, to understand prehistoric state change dynamics (Van Devender 1995) and the more recent shifts from 1858 (Fig. 2.6), and to predict future dynamics as part of modeling efforts (Objs. 1-4). Our approach to-date has been to use: (a) a detailed geomorphic map (Monger et al. 2006) to guide our experiments (*Landform*), (b) field sampling of soils at specific locations (e.g., *DesertSoils*; Gile et al. 2007), and (c) general soils maps from 1915 and 1968 *(SoilMaps)* combined with site-specific data and the geomorphology map for example to develop soil input parameters by depth for simulation models (Peters et al. 2010). Based on these efforts, **we hypothesize that three new soils maps are needed for improved estimates of soil characteristics through time for field studies and simulation modeling.** First, we will quantify the $\delta^{13}C$ and age (^{14}C) of the millimeter-thick laminar stratigraphy of $CaCO_3$ atop petrocalcic horizons to produce a detailed isotopic record of the last 30,000 years (Monger et al. 2009a). Second, we will use carbon isotopes and soil stratigraphy to generate a soils map that represents the condition of the landscape before the late-1800s desertification event (Objs. 1-3). Third, we will use digital soil mapping techniques (Browning and Duniway 2011) to predict the current distribution of key soil variables (e.g., surface texture, water holding capacity, depth to petrocalcic). This approach will: (1) build on past landform and parent material mapping (Monger et al. 2006), (2) integrate existing point data on soil properties (Duniway et al. 2010c,d), (3) utilize existing terrain and spectral GIS layers (IFSAR DEM, LandSat imagery, etc), and (4) collect new soils data as needed. These studies will be conducted in cooperation with the National Resource Conservation Service (NRSC), and will use their field and laboratory methodology (Monger et al. 2009b).

Obj. 5 (c) Mammalian community dynamics as drivers of alternative states *(Schooley, B. Bestelmeyer).* Variation in rodent abundance has cascading effects on arid ecosystems via selective herbivory, biopedturbation, and ecosystem engineering (Whitford and Bestelmeyer 2006, Bestelmeyer et al. 2007, Eldridge et al. 2009). Past monitoring of rodent populations (1995-2007; *SMES*) revealed large fluctuations in rodent numbers, and long-term effects in grasslands. In 2003, we expanded to include ecotones to determine if rodent community dynamics differ among ecosystem states (*Ecotone*). We also sought to test the zero-sum model positing that resources limit rodent community energy flux (Ernest et al. 2009). Initial results demonstrate high variability in rodent energy flux and biomass, and a complex relationship among rainfall, rodents, and vegetation state. **We hypothesize that these results either reflect effects of varying resource availability to rodents in wet-dry periods (Peters et al. 2012b) or top-down effects by mammalian predators (Meserve et al. 2003, Estes et al. 2009).** We will continue the rodent monitoring, and will add a new effort to provide density estimates of: (a) lagomorphs that rely on similar resources, and (b) mammalian carnivores, including coyotes, foxes, badgers, and bobcats. We will establish an array of non-invasive camera traps (methods in Rowcliffe et al. 2008) across grassland-shrubland ecotones (*Ecotone*) and co-located with other studies (Sections IV, V) to develop and test predictive models of species distributions linked to ecological states. *Cross-site studies:* Our small mammal monitoring is similar to efforts at SEV and SGS LTER sites, and the Mapimi Biosphere Reserve (Mexico), and complements the long-term study at Portal, AZ (Ernest et al. 2009). In addition, JRN and University of Illinois collaborators are comparing breeding bird populations across southwestern New Mexico in restoration treatments and remnant grassland and shrubland states.

Obj. 5 (d) Land-atmosphere interactions and broad-scale state changes *(Tweedie, Rango).* Grassland-shrubland transitions result in modifications to the surface water and energy balance at local to regional scales (Dugas et al. 1996, Kurc and Small 2004). These changes determine soil moisture-vegetation-precipitation feedbacks (Eltahir 1998, Mendez-Barroso and Vivoni 2010), and influence, to some extent, boundary layer dynamics, convective potential, and rainfall generation (Dekker et al. 2007). However, these relationships have not been examined both locally within one site with a history of state changes and across sites in a spatially variable region. **We hypothesize that differences between grasslands and shrublands in partitioning of sensible and latent heat flux, soil and vegetation albedo, and aerodynamic roughness have consequences for plant available water with feedbacks to future transitions, and lead to regional changes in precipitation that are robust across sites differing in climate, soils, and land-use history.** This hypothesis will be tested by combining on-going and future planned observations and UAV imagery at three eddy covariance towers: (1) *TW* upper bajada creosotebush-mesquite shrubland, (2) *CEC* upper bajada creosotebush site, and (3) NEON basin floor black grama grassland (future installation). Two sites have on-going vegetation, soil water, and atmospheric data collection following standard AmeriFLUX protocols (*TW, CEC*), while the third is planned. Long-term ANPP, biomass, and rainfall data are available (*NPP*, Peters et al. 2012b). UAV imagery will quantify vegetation cover and bare gap size distributions. Multi-year datasets will be used to evaluate effects of vegetation state on albedo, roughness, and energy partitioning, and resulting effects on plant available water. These datasets will serve as a baseline for ENSEMBLE modeling and a numerical weather model to evaluate the consequences of surface conditions to regional rainfall generation and to future states (Beltran-Przekurat et al. 2008, Vivoni et al. 2009). *Cross-site studies:* Data from the SEV LTER (creosotebush, grasslands) and Santa Rita NEON (creosotebush) sites will enable regional assessments of land-atmosphere interactions. These comparisons will determine if ecosystem state overwhelms variation in soils, land-use history, and amount and/or seasonality of PPT. Because measurements at the JRN tower sites are based on NEON specifications, we will compare our results with additional NEON sites as they come on-line.

CHIHUAHUAN DESERT REGIONAL DYNAMICS

(Skaggs, Sayre [co leads], Havstad, B. Bestelmeyer, Collaborator: Buenemann [NMSU])

Given the importance of human activities to transitions between states, and their increasing influence near the Jornada, an explicit accounting of these activities and their interactions with desert systems is needed to meet our overall goal. The history of the northern Chihuahuan Desert includes the prevalence of humans starting > 10,000 years ago (Fredrickson et al. 1998; 2006). In the 1500s, Europeans transported goods and animals across the Jornada Basin along the Camino Real from Mexico City to Santa Fe (Havstad et al. 2006). The region continues to change rapidly: the population of Doña Ana County increased 20% from 2000 to 2010, compared with 13% for New Mexico and 10% for the U.S. The addition of human dimensions to the JRN is an important step in understanding regional dynamics and in incorporating perspectives and methods that ensure our science is relevant for advancing conservation, management, and policy initiatives in what has been termed 'The New West' (Riebsame 1997).

In LTER-V, we initiated studies of linked human-natural ecosystems through data acquisition and mapping of socioeconomic variables in selected areas of southern NM (Buenemann and Wright 2010, Skaggs et al. 2011). In LTER-VI, we propose to build on these foundation studies to provide a more mechanistic understanding of how human and natural systems are coupled to result in state changes with consequences for ecosystem services (Section VI). We propose to: (a) quantify land-use change and trends in socioeconomic drivers, (b) characterize effects of ecological transitions in driving land management decisions and land-use patterns, (c) disentangle the relative importance of human-caused drivers (e.g., land management, land-use choice) compared with biophysical drivers (e.g., climate) in causing changes in socio-ecological states, and (d) determine the importance of local ecological knowledge (LEK) to these transitions. We will address two objectives: (a) compare trends in climatic and anthropogenic drivers with changes in socio-ecological states throughout the northern Chihuahuan Desert, and (b) examine the importance of LEK through detailed case studies at the individual ranch scale.

Obj. 6 (a) Broad-scale patterns and trends in drivers and changes in socio-ecological states. Land-use change—conversion of both croplands and rangelands to urban, suburban, and exurban uses—has been rapid and widespread throughout the region and the western US in recent decades (Brown et al. 2005). While the economic driver of land-use change is clear —rising land values (Torell et al. 2005)—the social-ecological causes and consequences are more complex. For example, deciding to sell a ranch for development often depends on socio-economic contingencies, such as debt, inheritance issues, and cattle prices, and on ecological factors, such as drought. In southern NM, ranch abandonment can result from security issues in raising livestock along the U.S.-Mexico border. Land-use change may also be subject to spatial context: ranchers are likely to sell if surrounding ranches are converted to residential property (Liffmann et al. 2000). Initial JRN research documented spatial variation in ranch stability as a result of many of these factors, including ranch operators' perceptions of past, present, and future causes of ranch impermanence. **We hypothesize that biophysical factors, transportation corridors, land values, proximity to the urban fringe, and proximity to the US-Mexico border determine where and when rangelands have undergone a change to residential land uses, disinvestment or investment, and reduced or increased management intensity.** We will test this hypothesis using historic aerial photographs and remote sensing imagery to reconstruct land-use change over the past 40-80 years. Methodologies for assessing land use change will be continued and refined (Hestir 2011). We will analyze patterns of change against climatic, economic, and demographic data (land values, population growth), and infrastructure data (e.g., roads and highways). Spatial analysis of survey data for impermanence factors and ranch ownership data collected under LTER-V will continue.

Obj. 6 (b) The importance of LEK to fine-scale transitions. The fine-scale history of state transitions is not well known outside of research sites such as the Jornada. Fortunately, there is a large store of fine-scale LEK among long-time (multi-generation) ranchers in the region, as well as archival data compiled by public land agencies that have leased rangelands to ranchers since the early 1900s. However, these data have not been sufficiently catalogued, and ranchers' personal knowledge is at risk of loss before it can be captured in a form usable to the research community. With support from JRN supplemental funds (2009-2011), we began to collect LEK from long-time land managers to identify the climatic and management drivers of state transitions at small spatial (plots, pastures) and short (months, years) and long (40-100 y) temporal scales. We also began utilizing archival data from the Bureau of Land Management and the US Forest Service (Sayre 2011). This work demonstrated that the dates and sequences of climatic and human events that preceded, and potentially triggered, transitions between ecological states in the past can be identified. **We hypothesize that similar ecological sites within the region have experienced similar state changes in the past 120 years, but at different points in time. Specific combinations and sequences of land management practices and biophysical factors determine when sites crossed thresholds between states. Similar threshold changes can result from**

different combinations, sequences, and intensities of human and biophysical drivers. Using methods from G. Kofinas et al. (unpublished), we will interview longtime owners and managers (≥3 generations) to reconstruct the history of management practices and changes in vegetation and other biophysical attributes for specific ranches and locations within ranches. Maps will be compared with other sources of historical and spatial data (agency archives, remote sensing, historic aerial photography). Field research will be conducted to ground-truth imagery. We will analyze observed state changes relative to climate and management (e.g., stocking rates), and to compare results across ranches to identify patterns over space and time, including sequences of social and ecological events that may have precipitated vegetation state changes. *Cross-site analyses:* This work will continue to compare 11 sites in the LTER network that were originally funded by an LTER Social Sciences Supplement to the MALS Project. Initial results show important variation across sites in both the rates and patterns of change, and the importance of LEK compared with other drivers.

VI. Alternative futures in the Chihuahuan Desert: consequences for ecosystem services

(Sala, Sayre [co leads], Skaggs, Havstad, B. Bestelmeyer, Archer)

The northern Chihuahuan Desert is experiencing rapid changes as a result of changing environmental drivers and increasing demands on ecosystem services (Havstad et al. 2007). There is also a significant change in the scale of the stakeholders demanding services from these ecosystems. In the past, most stakeholders lived in the region. Now, a new cohort of remote stakeholders interested in regional or global ecosystem services is influencing the future of the region. For example, communication innovations in the 1980s fueled both the migration of retirees and the conservation interests of wealthy younger adults and professionals in high-tech businesses living and working elsewhere (Nord and Cromartie 1999).

We will build on our expertise in developing global scenarios to develop alternative futures for the northern Chihuahuan Desert (Sala et al. 2006). As a first step, we will convene a workshop to examine each scenario in light of regional and global variation in the human and natural environment. This workshop will bring together regional specialists (e.g., ecologists, sociologists, economists, landscape geographers, agriculturalists, urban planners, political scientists, community leaders) and experts in scenario building. Based on results from this workshop, we will develop region-specific scenarios using tools in the Millennium Ecosystem Assessment (2005) combined with our successful relationships with community leaders, state, and federal agencies. We will use the methodology previously applied to Northern Wisconsin (Peterson et al. 2003).

Scenarios will be based on regional attitudes and motives of agricultural, industrial, and residential landowners combined with historical relationships linking drivers and changes in socio-ecological states (Section V. Obj. 6). Recent research shows that a high percentage of the region's cattle industry is not driven by traditional business objectives, but rather by lifestyle or consumptive objectives (Gentner and Tanaka 2002, Wood 2003). Attitudes toward the environment, agriculture, and government vary among New Mexico residents (Skaggs and VanLeeuwen 2004), and land purchase preferences are highly variable among Doña Ana County homebuyers (Harper and Skaggs 1999). Modifying these scenarios for a local to regional application will demonstrate effects of significant changes in population pressure, policies, and institutions on goods and services provided by regional natural resources and the quality of life that may result. For example, one plausible regional scenario for southern New Mexico compatible with the global "Adapting Mosaic" scenario is a reallocation of surface and ground water supplies in the Rio Grande Basin from agriculture to domestic uses. This reallocation would allow the population of the region to grow by an additional 1.6 million people with important ecological, social, and political consequences for neighboring wildland areas, such as the Jornada, and feedbacks to human behavior. Given our proximity to the U.S. – Mexico border (ca. 80km), modifications to border security policies at a national level would lead the region into "Order from Strength" or "Global Orchestration" scenarios that could overwhelm local and regional decisions. Finally, we will examine the socio-ecological consequences of each potential scenario to Doña Ana County and the rest of the northern Chihuahuan Desert, and will report our findings to the regional specialists.

VII. Integration and synthesis

Current paradigms for drylands that emphasize desertified shrublands as a stable endpoint driven by broad-scale drivers (e.g., drought, fire, livestock overgrazing) and local plant and soil properties can not account for the diversity of state change dynamics, spatial heterogeneity in rates and patterns of shrub expansion, and complexity of human activities that are prevalent in these systems globally. Our research program integrates an evolving multi-scale conceptual framework with accessible data (legacy and proposed), tools for monitoring, assessment, and prediction of socio-ecological state changes, and information transfer to a broad audience in ways that will advance conservation efforts and the sustainable use of drylands while also making important contributions to a broader theory of state changes. This integration is only possible with a collaborative team of PIs of diverse interests and expertise that share a commitment to (*i*) solving problems using long-term, site-based research combined with cross-site or -system comparisons, and (*ii*) transferring information to current and future generations interested in sustaining the broad range of ecosystems and their services in the Earth system.

Our landscape linkages framework of multiple interacting spatial and temporal scales will significantly advance understanding of ecosystem dynamics, at local scales and as dynamics propagate across scales to generate emergent behavior. The proposed collaborations with the SEV LTER represent an excellent opportunity to integrate their work on plant-microbial interactions with our extensive body of work on plant-to-patch-scale processes (e.g., Havstad et al. 2006) and to uniquely advance our understanding of how fine-scale processes mediate local ecosystem dynamics. The JRN LTER-VI focus on patch-to-landscape scale redistribution of resources and its mediation by spatial and temporal context represents the next logical step for determining which factors emerging from plant-scale processes feed forward to influence landscape-scale dynamics. Furthermore, we recognize the importance of continental- and global-scale teleconnections between drylands and other biomes (Peters et al. 2008; Peters 2011). Involvement with non-LTER scientists with expertise in large-scale spatial analysis and continental-scale research will place Jornada science within a much broader spatial and scientific context.

The LTER-VI plan is an ambitious expansion that logically builds upon and extends the desertification and grassland-to-shrubland transition themes of earlier funding cycles. The inclusion of additional classes of state change (grass recovery, shrubland transitions, novel ecosystems, human-dominated states) will be challenging, but doable, given the extensive knowledge base and good working relationships among our team of PIs, staff, and collaborators. Logistical constraints dictate our research focus on climate and human activities as drivers of change, but our research plan will strategically examine the role of fire and livestock grazing within this context. Although the studies associated with each class of dynamics were described separately in Section V, we are poised to capture synergies that will emerge from comparisons: (a) across classes of dynamics, (b) between geomorphic units, (c) between natural and human-dominated states, and (d) across sites within and beyond the LTER Network. Our ENSEMBLE simulation model will be instrumental in integrating this information, and in evaluating the impacts of environmental change on a broad range of ecosystem services for scenarios of future states likely to accompany changes in global environmental drivers. Finally, we will continue our emphasis on data and information accessibility (e.g., EcoTrends Project), and making our science exciting, relevant, and applicable to students, educators, scientists, the general public, land managers, and decision makers.

3. BROADER IMPACTS: EDUCATION AND OUTREACH

We have five major parts to our outreach program that lead to broader impacts of our research: education (K-gray), outreach to land managers and scientists, media communications, technology development and transfer, and data and information accessibility. Broader impacts are summarized here, and detailed in the CV of each PI.

Education. (a) Schoolyard LTER (sLTER) – We propose to continue our strong and effective collaboration among three entities (the nonprofit Asombro Institute for Science Education [AISE], the USDA-ARS Jornada Experimental Range, and the JRN LTER) that result in a highly successful Jornada

Schoolyard LTER led by S. Bestelmeyer. All programs are characterized by: (i) a tight connection to current and past LTER research on state changes in Chihuahuan Desert ecosystems, (ii) hands-on and inquiry-based activities, and (iii) a close alignment with New Mexico and Texas state education standards in science and math. Implementation Plan: we propose to continue five major programs and to add two new programs: (1) *Schoolyard Science Studies* (Schoolyard Desert Discovery Program) – We will continue to provide 40 activities for the schoolyard and/or classroom developed by AISE staff working with JRN scientists. Activities mirror JRN research with modifications for schoolyard settings. Activities are divided into eight topic areas with a handbook and Science Investigation Kit containing background material, teacher instructions, tips for completing the project, sample tables and graphs, and reproducible student pages in English and Spanish. We will create additional activities modeled after new research, on topics such as decomposition, seedling establishment, and ecosystem services. (2) *Field Trips* – Students will continue to attend field trips to the Jornada and/or the Chihuahuan Desert Nature Park, the 935-acre facility owned by the AISE. Students will rotate through grade-level, hands-on activity stations chosen by their teachers. New activity stations will be added based on current JRN research. (3) *Classroom / Schoolyard Programs* – AISE staff members will continue to visit classrooms to present one-hour, inquiry-based science programs using Schoolyard Desert Discovery activities. Based on past demand, we expect to deliver 30 one-hour programs per month. (4) *Teacher Workshops* – We will conduct at least six workshops for 15 teachers each on existing and new Schoolyard Desert Discovery activities. Teachers of a particular grade level will be selected for each workshop. During the course of six years, each grade level will be represented. (5) *Family Education Events* – We will host a minimum of 24 family-friendly events at the Chihuahuan Desert Nature Park and other venues. In addition to continuing popular events (e.g., the Kids Passport to the Desert event), we will infuse science activities that can be done in backyards and local open space into other community events, such as those that aim to reduce childhood obesity. We anticipate an average of 100 participants at each event. We will also add two new programs: (6) *Desert Data Jam* – As the amount of long-term ecological data continues to increase, the need for students skilled in analyzing, synthesizing, and presenting data is critical. We propose to begin a new program to encourage students to use publically available data from the JRN and EcoTrends to create visualizations that transmit findings to non-scientists. (7) *Graduate Student Participation in K-12 Education* - We propose to strengthen linkages between JRN graduate students and the K-12 community, similar to NSF's GK-12 Program to enhance scientific literacy. JRN funded graduate students will be expected to engage in a minimum of 10 hours of sLTER activities that range from direct interactions with students, teachers, and/or the general public to assisting with the creation and testing of activities. We expect that graduate students will gain: (i) communication skills, (ii) resume-building experiences, and (iii) a better understanding of the realities of science education; and K-12 teachers and students will gain: (i) better understanding of local, up-to-date ecological research, and (ii) access to role models.
Evaluation: We propose to continue to use extensive formative and summative evaluation tools to assess achievement of program goals. Tools include teacher surveys, Draw A Scientist tool, and student comments that highlight misperceptions and form the basis for modifying or developing new programs.
Outcomes: (i) At least 61,200 K-12 students with increased knowledge of desert ecology and the process of science, and decreased stereotypes about scientists that will encourage students from underrepresented groups to consider science as a career option; (ii) More than 90 teachers with experience teaching desert ecology and the materials needed for hands-on science activities in their classrooms and schoolyards; (iii) A cadre of JRN LTER graduate students with an appreciation for the joy and challenges of working with the K-12 community to promote broader impacts from their own research; (iv) At least 2,400 members of the general public with knowledge about the local ecosystem and current LTER research.

(b) Undergraduate and graduate education (led by Monger) – We will continue to support a large number of undergraduates part-time during the academic year and fulltime in summers, including two REUs per year. We will also support nine NMSU M.S. students. We will prioritize M.S. students because they are well-suited to the studies proposed here, and this maximizes the number of students and investigators directly involved in JRN-funded projects. Prioritizing NMSU students will optimize resources by reducing overhead and out-of-state travel costs, and will allow greater opportunities for minority students from this Hispanic-serving institution to participate. We will continue to provide partial support for Ph.D. students funded by additional sources, such as teaching assistantships and other awards.

Outreach to land managers and scientists. We propose to continue four elements of our outreach led by Havstad and Herrick. (1) Our ca. two-dozen specific cooperative research agreements with a cross-section of clients and stakeholders promote two-way communication and collaboration. (2) Targeted interactions with resource management practitioners (private, public) include workshops, seminars, and service on boards of directors. Topics include rangeland health evaluations, data collection and resulting analyses associated with the National Resource Inventory, and development of ecological site descriptions. Each year, >1000 hours are devoted by JRN personnel to these outreach activities. (3) Outreach to scientific audiences includes our annual research symposium, periodic newsletter (Jornada Trails), and the development of internet-based systems for sharing knowledge and information (www.ecotrends.info, www.landscapetoolbox.org). The Jornada Basin symposium is scheduled each July, and has attracted a growing audience over the past 19 years. We employ a web-based simulcast to reach individuals off-site, and provide Spanish translations. Our newsletter is locally produced and reaches researchers, administrators, and land managers across the US and internationally with a mailing list of > 350. It is also available on our web site (http://jornada-www.nmsu.edu). We are expanding our outreach internationally through the internet with documents available in multiple languages, workshops, and participation in UNCCD negotiations and other events, including representation as the US Science and Technology correspondent (Herrick). (4) Direct consultation and advice is provided to leadership of federal land management agencies and technical service providers based in Washington, DC, and national governments on other continents. For example, we directly provide science-based recommendations for resource assessment and monitoring programs across the US and Mongolia.

Technology development and transfer. We propose to continue the development and subsequent public release of technologies associated with the ease of acquisition and use of imagery from UAVs led by Rango. We will integrate and test more sophisticated sensors, including thermal, hyperspectral, and lidar sensors for more detailed characterization of vegetation, soil, and terrain parameters over larger areas.

Information accessibility. We propose to continue development of the EcoTrends Project to make long-term data easily accessible for download and use by a broad audience (Peters et al. 2012a). This project began with NSF, USDA, and NMSU funding in 2006, and has grown to include > 50 sites and several hundred on-line datasets. We plan to add more data sets with national coverage through time (e.g., climate, atmospheric deposition) and across space (e.g., soils, land use/land cover, imagery). We are redesigning the EcoTrends web site (http://www.ecotrends.info) to include different kinds of data and additional national and international sites. We are also developing analytical tools for data use.

Communication with the media. We will continue to communicate with the media, primarily through NMSU. JRN research appears on average every two years, either in the NMSU Research News magazine published by the Vice President for Research Office, or as a News Release from the University Communications & Marketing Services office. These articles are often picked up by the local newspaper (Las Cruces Sun News) and sometimes more broadly by national papers, including most recently by USAToday.

4. RESPONSE TO 2009 NSF SITE REVIEW TEAM

The NSF review team provided constructive comments in five areas (site science, education and outreach, network-level interactions, information management, site management). We agreed with all of their suggestions and recommendations, and have done our best to incorporate these into our program given limited resources. Their suggestion to more explicitly link current and proposed research with our long-term, core data sets and models was particularly helpful and guided the development of this renewal proposal. Detailed responses to specific suggestions are given in a 4 January 2012 letter to Dr. Twombly.

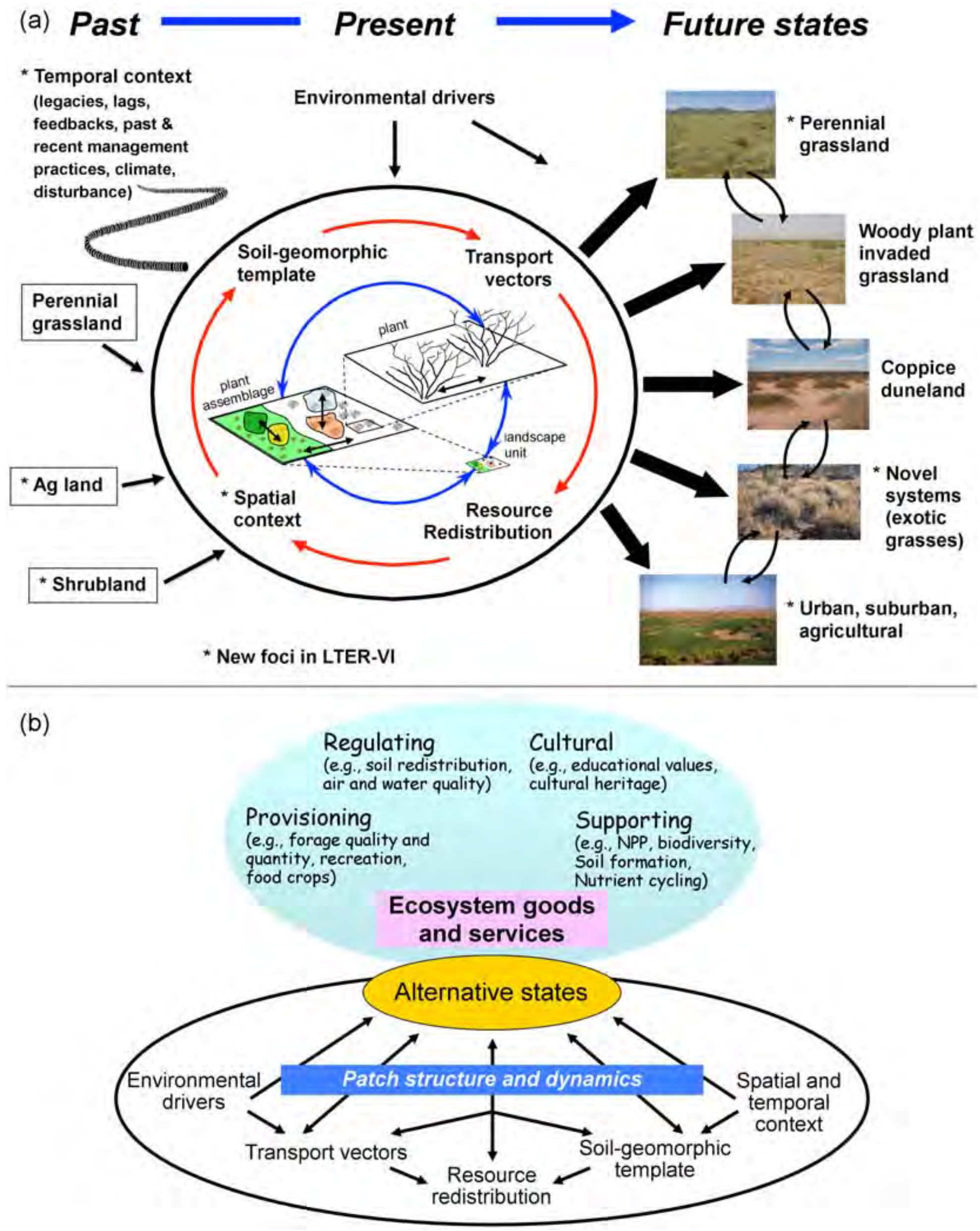

Fig. 2-1. (a) Landscape linkages framework for state change dynamics and (b) the relationship between state changes and the provisioning of ecosystem goods and services. Spatial and temporal variation in state changes and ecosystem function reflect historical legacies (e.g., land use) and environmental drivers (e.g., precipitation, temperature, human activities) interacting with system structural properties (spatial context [patch characteristics, adjacency, contingency], transport vectors [wind, water, animals], and the soil-geomorphic template) to influence resource redistribution within and across a range of scales, from individual plants to groups of plants (patches) and landscape units. New foci in LTER-VI include (*i*) a more detailed accounting of how spatial and temporal context influence function, (*ii*) the inclusion of additional historic (agricultural land, shrublands) and future states (novel systems, human systems [urban, suburban, agricultural]), and (*iii*) quantification of state change effects on ecosystem provisioning of goods and services in drylands.

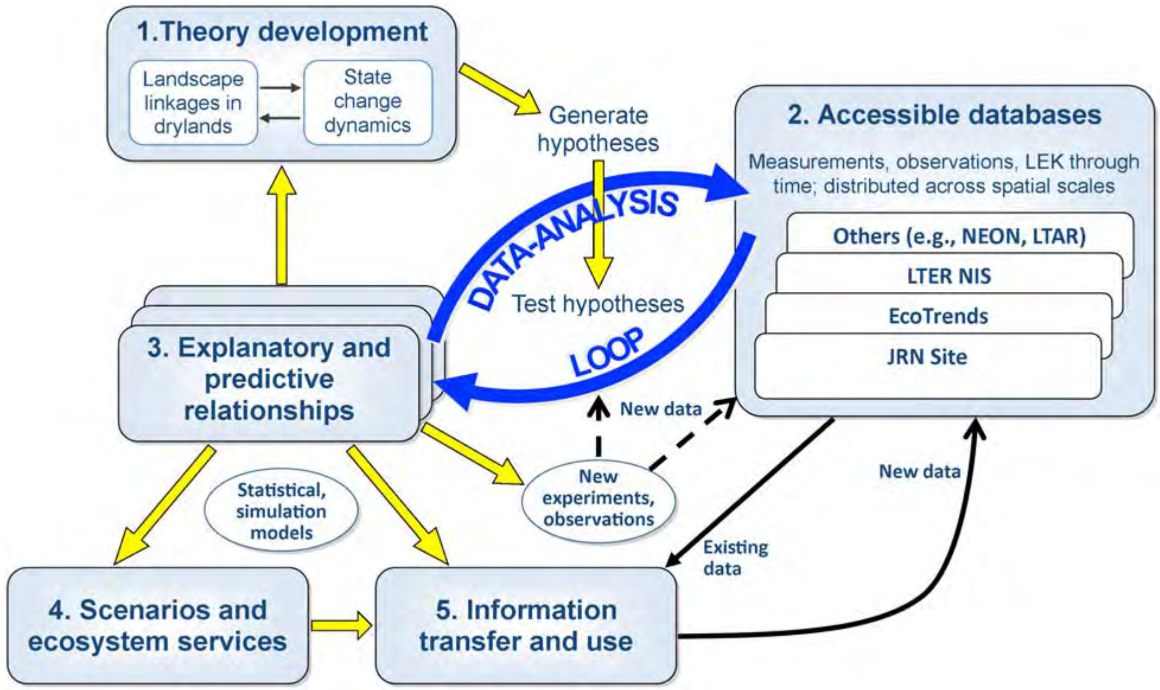

Fig. 2-2. Jornada LTER research will result in five linked major outcomes or products (boxes and yellow arrows): (1) an evolving broad theory of state change dynamics and our Landscape Linkages conceptual framework, (2) a JRN site database of accessible short- and long-term data, observations, and local ecological knowledge (LEK), derived data products, initial analysis and visualization tools, and access to data in a suite of other databases, (3) explanatory and predictive relationships among drivers, patterns, and processes that can be used to (4) develop scenarios of alternative human- and natural-dominated states with assessments of their impacts on ecosystem services; and (5) user-friendly information transfer to a broad audience that can result in the addition of new data to a common database (black arrows). New insights provided by the relationships lead to further theory development.

The "Data-Analysis Loop" (shown by coupled blue arrows) is unique to research sites, such as LTER sites, where a common database from many studies and investigators can be accessed before new experiments or observations are collected. Multiple iterations between the database and analyses for explanatory or predictive relationships are possible that can be used to optimize resources by strategically designing new experiments and collecting additional measurements, as needed (dashed black arrows). This Data-Analysis Loop provides one step beyond the vision of Peters (2010) to show the value of common site- and network-level databases, integrated data, and derived data products, and meets several of the recommendations in a recent report, yet leaves open the question of responsibility for integration, hosting, and managing data from multiple networks (R.J. Robbins. 2011. Data management for LTER: 1980-2010. Position paper prepared in conjunction with the NSF 30-year review of LTER).

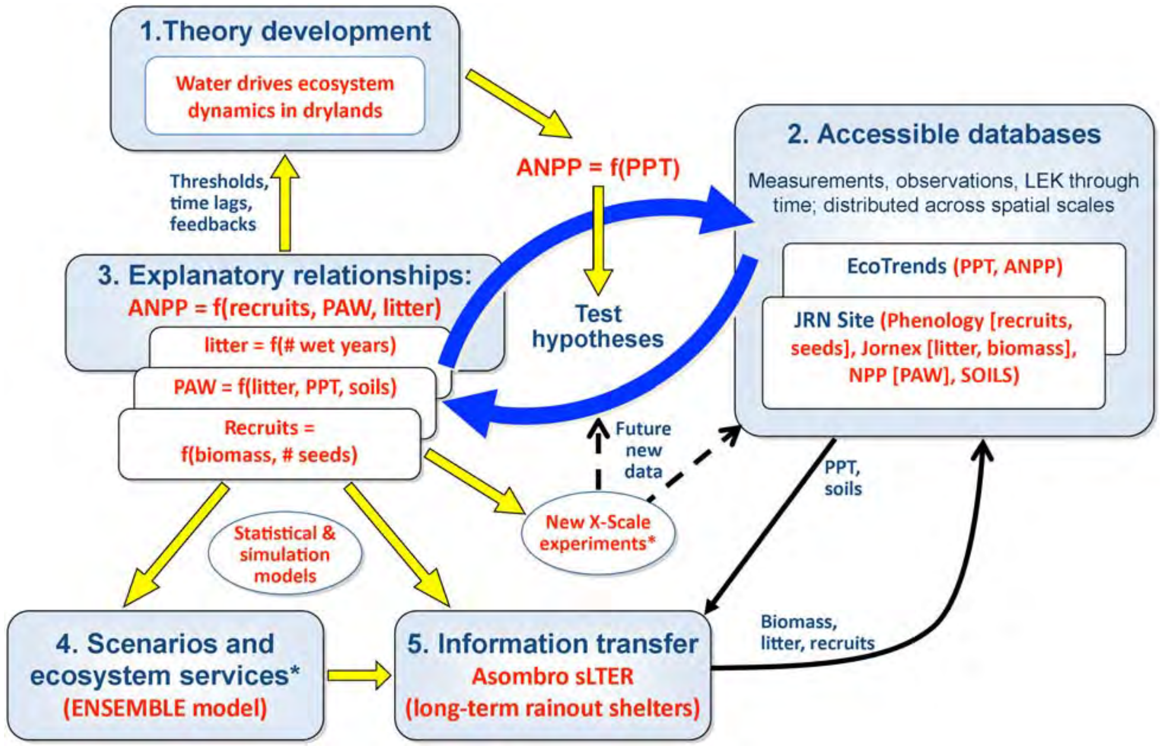

Fig. 2-3. An example implementation of Fig. 2-2 from a recent JRN study (red text shows ongoing efforts described in Section 1; * text shows proposed efforts detailed in Section 2.V). Based on theory and studies from many terrestrial ecosystems, aboveground net primary production (ANPP) in a given year at a site was expected to be related to the amount of precipitation in that year. Long-term ANPP (*NPP Study*) and precipitation [PPT] data (1989-2010) from the Jornada in the EcoTrends database (http://www.ecotrends.info) were used to test this hypothesis. A linear relationship was found in average rainfall years and during a long-term drought, but the relationship did not hold during a 5-year sequence of wet years (Peters et al. 2012). Data from additional long-term studies (*Phenology, Jornex*, Plant available water measurements [PAW] at the NPP locations) showed that ANPP is nonlinearly related to the number of recruits, PAW, and litter that accumulates through time as the number of wet years increases. The positive feedbacks between litter and PAW leads to more recruits and greater biomass than expected based on rainfall alone (Peters et al. submitted). These results will be tested in our new *X-Scale Study,* and will be used to parameterize our ENSEMBLE model to examine consequences of a sequence of wet years to grass recovery and a state change reversal from shrublands to grasslands. Findings are being used to modify our Landscape Linkages framework, and in cross-site analyses to further develop a general theory of state change dynamics (e.g., Bestelmeyer et al. 2011). Information transfer to K-12 students and educators as well as the general public is occurring through specialized lesson plans and activities focused on rainout shelters installed at the Chihuahuan Desert Nature Park.

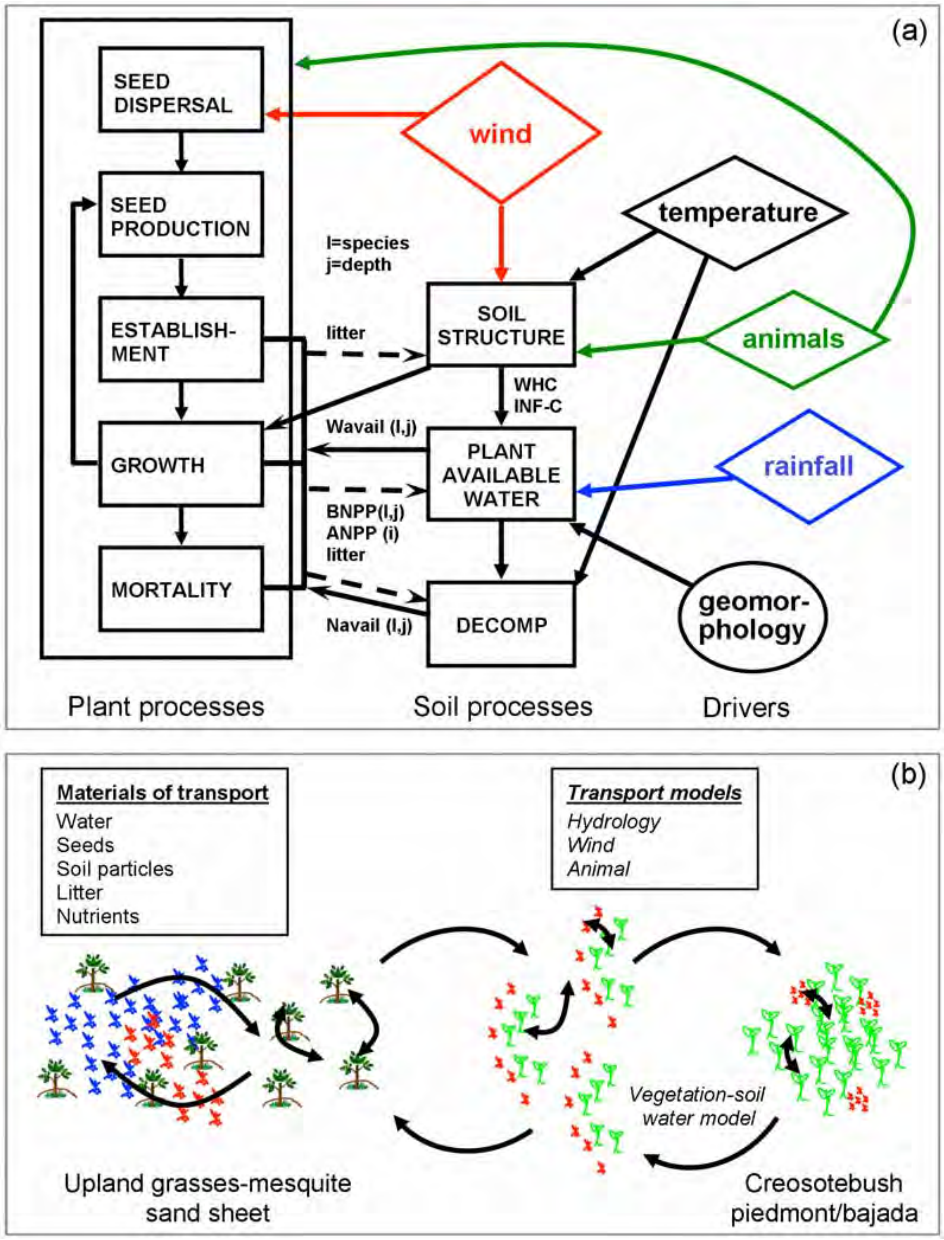

Fig. 2-4. ENSEMBLE model: (a) simulates animal, plant, and soil processes within a spatial unit as well as transport vectors (wind, water, animals) that redistribute materials among units. Time scales vary from days to decades depending on the process simulated. Spatial scales range from individual plants to groups of plants, to landscapes with contrasting geomorphic units to watersheds. Environmental drivers are mediated by geomorphic and topoedaphic properties and include climate and disturbances, such as human activities; (b) links existing models of vegetation and soil processes at the scale of individual plants (ECOTONE) with transport models for wind (SWEMO), water (tRIBS), and animals. Transfers of materials are simulated within and between geomorphic/topoedaphic landscape units across scales ranging from individual plants to watersheds.

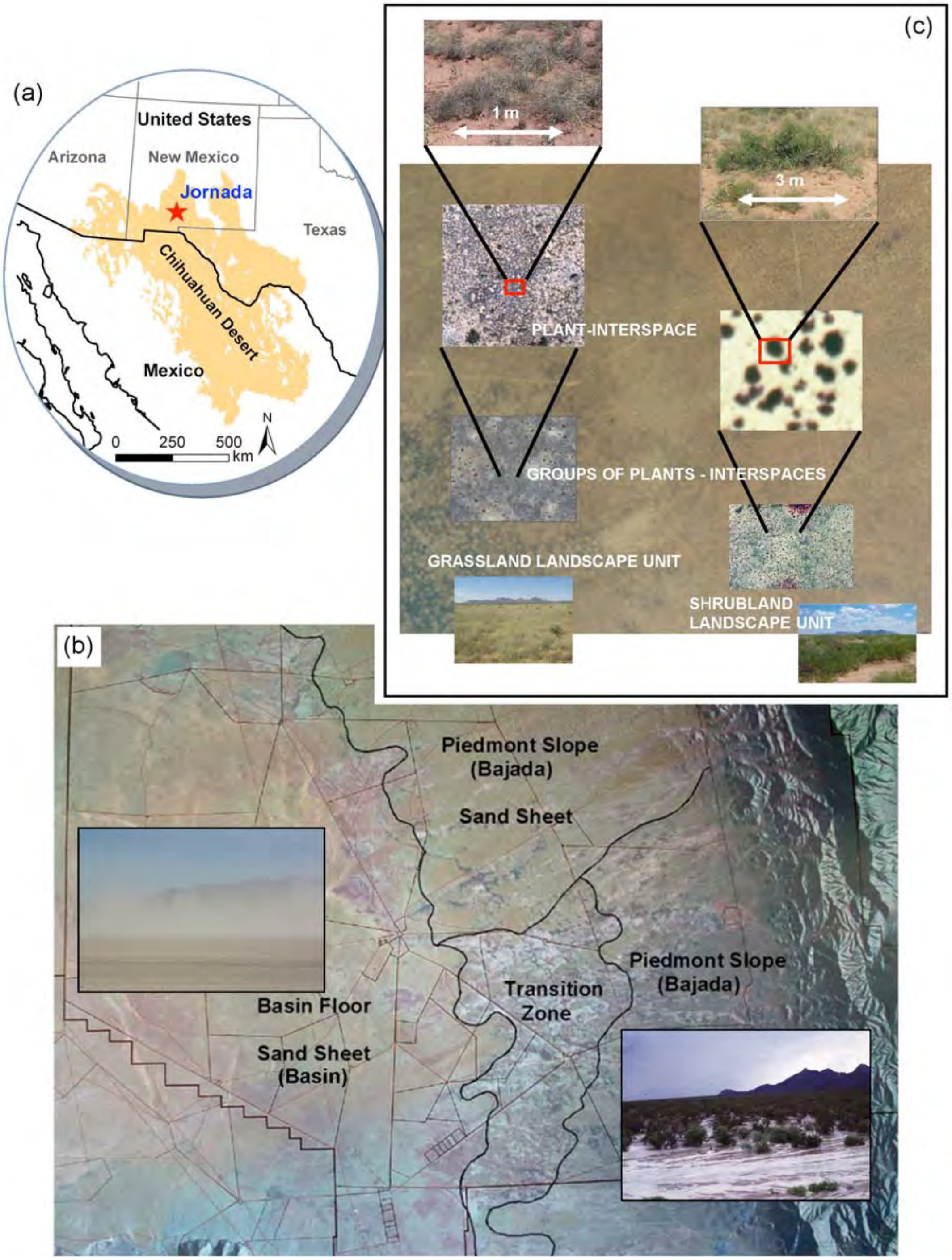

Fig. 2-5. (a) Location of the Jornada LTER in the northern Chihuahuan Desert; (b) Location of the major geomorphic units at the Jornada where our research is focused: the basin floor sand sheet (wind-dominated transport) and the piedmont slope bajada (water-dominated transport); and (c) hierarchy of spatial scales for the redistribution of resources in our conceptual framework. Dust photo [left] and water erosion [right] inserts in (b) illustrate active material transport.

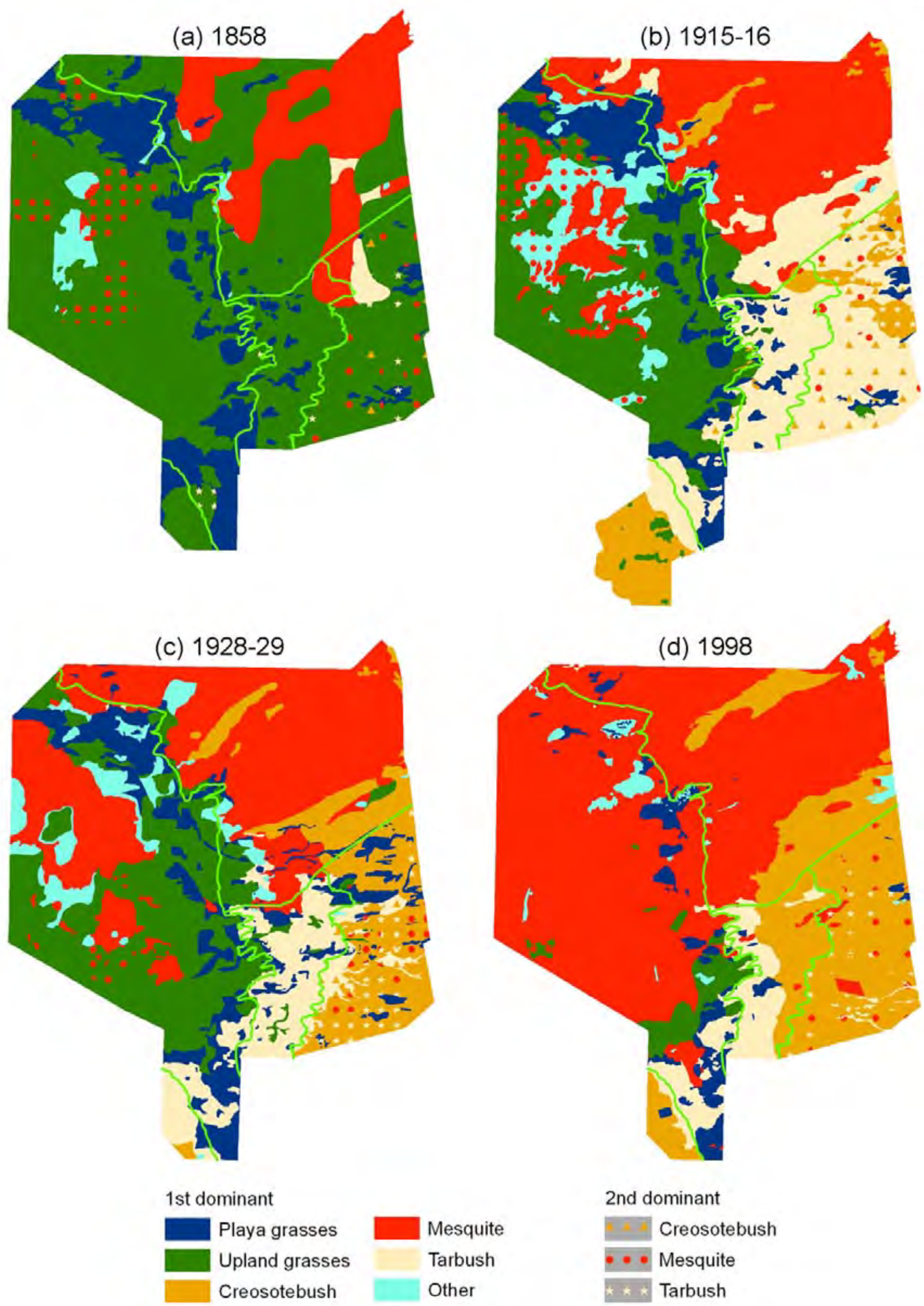

Fig. 2-6. Jornada vegetation maps showing first and second dominant species: (a) 1858, (b) 1915-16, (c) 1928-29, (d) 1998 (modified from Gibbens et al. [2005]). Note transitions from grass to shrub dominance; and also shifts between shrub states (e.g., tarbush vs. creosotebush). Prior JRN LTERs I-V emphasized the former; LTER-VI will begin to address the latter.

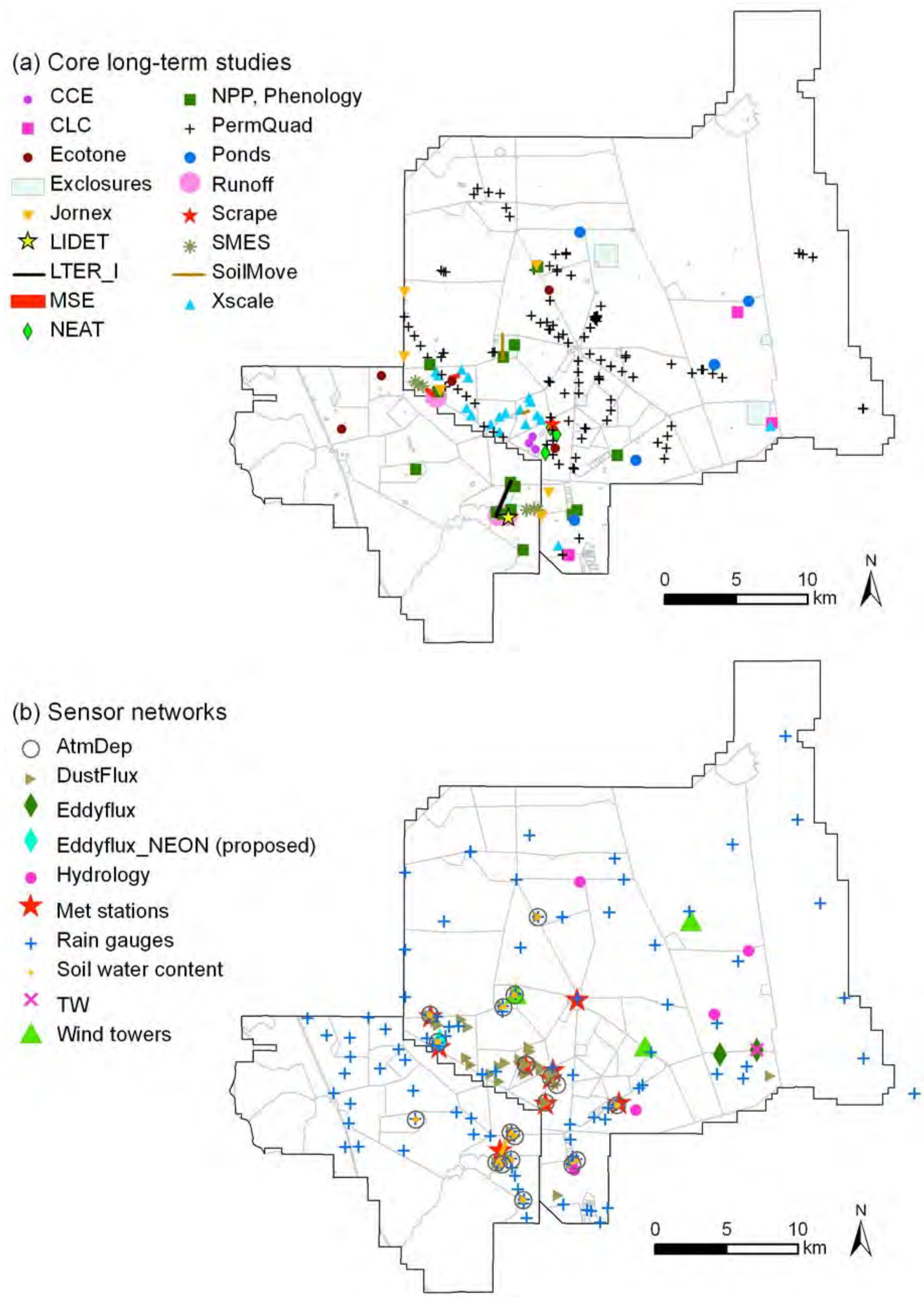

Fig. 2-7. Jornada research site showing locations of (a) core long-term LTER studies, and (b) sensor networks.

5. REFERENCES CITED

Abrahams AD, Parsons AJ, Wainwright J. 2003. Disposition of rainwater under creosotebush. Hydrological Processes 17:2555–2566.

Allington GRH and Valone TJ. 2010. Reversal of desertification: the role of physical and chemical soil properties. Journal of Arid Environments 74:973-977.

Alvarez L, Epstein HE, Li J, and Okin GS. 2011. Spatial patterns of grasses and shrubs in an arid grassland environment. Ecosphere 2:art103.

Alvarez L, Epstein HE, Li J, and Okin GS. 2012. Aeolian process effects on vegetation communities in an arid grassland ecosystem. Ecology and Evolution (In Press).

Archer S. 1989. Have southern Texas savannas been converted to woodlands in recent history? American Naturalist 134:545-561.

Archer S. 1994. Woody plant encroachment into Southwestern grasslands and savannas: rates, patterns and proximate causes. In: Vavra M, Laycock WA, and Pieper RD (Eds). Ecological implications of livestock herbivory in the West. Society for Range Management, Denver, CO.

Archer S. 2010. Rangeland conservation and shrub encroachment: new perspectives on an old problem. In: du Toit J, Kock R, and Deutsch J (Eds). Wild Rangelends: Conserving Wildlife While Maintaining Livestock in Semi-Arid Ecosystems. Wiley-Blackwell Publishing, Oxford, England.

Archer S and Bowman A. 2002. Understanding and managing rangeland plant communities. In: Grice A and Hodgkinson K (Eds). Global rangelands: progress and prospects. CAB International, Wallingford, Oxon, United Kingdom.

Archer S, Davies K, Fulbright T, McDaniel K, Wilcox B, and Predick K. 2011. Brush management as a rangeland conservation strategy: a critical evaluation. In: Briske D (Ed). Conservation benefits of rangeland practices: assessment, recommendations, and knowledge gaps. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

Archer S and Predick K. 2008. Climate change and ecosystems of the Southwestern USA. Rangelands 30:23-28.

Archer S, Schimel DS, and Holland EA. 1995. Mechanisms of shrubland expansion: land use, climate or CO_2? Climatic Change 29:91-99.

Arnalds O and Archer S (Eds). 2000. Rangeland desertification. Kluwer Publishing Company, Dordrecht, the Netherlands.

Asner GP, Elmore AJ, Olander LP, Martin RE, and Harris AT. 2004. Grazing systems, ecosystem responses, and global change. Annual Review of Environment and Resources 29:261–299.

Barger NN, Archer SR, Campbell JL, Huang CH, Morton J, and Knapp AK. 2011. Woody plant proliferation in North American drylands: a synthesis of impacts on ecosystem carbon balance. Journal Geophysical Research – Biogeosciences 116:G00K07; doi:10.1029/2010JG001506.

Barnes PW, Throop HL, Hewins DB, Abbene ML, and Archer SR. 2012. Soil coverage reduces photodegradation and promotes the development of soil-microbial films on dryland leaf litter. Ecosystems. DOI: 10.1007/s10021-011-9511-1.

Beltran-Przekurat A, Pielke RA, Sr, Peters DPC, Snyder KA, and Rango A. 2008. Modeling the effects of historical vegetation change on near-surface atmosphere in the northern Chihuahuan Desert. Journal of Arid Environments 72:1897-1910.

Bestelmeyer BT, Ellison AM, Fraser WR, Gorman KB, Holbrook SJ, Laney CM, Ohman MD, Peters DPC, Pillsbury FC, Rassweiler A, *et al.* 2011a. Analysis of abrupt transitions in ecological systems. Ecosphere 2: art 129.

Bestelmeyer BT, Goolsby DP, and Archer SR. 2011b. Spatial perspectives in state-and-transition models: A missing link to land management? Journal of Applied Ecology 48: 746-757.

Bestelmeyer BT, Khalil NI, Peters DPC. 2007. Does shrub invasion indirectly limit grass establishment via seedling herbivory? A test at grassland-shrubland ecotones. Journal of Vegetation Science 18:363-370.

Bestelmeyer BT, Peinetti RH, Herrick JE, Steinaker D, and Adema E. 2011c. State-and-transition model archetypes: A global taxonomy of rangeland change. International Rangeland Congress IX:60.

Bestelmeyer BT, Tugel AJ, Peacock GL Jr, Robinett DG, Shaver PL, Brown JR, Herrick JE, Sanchez H, Havstad KM . 2009. State-and-transition models for heterogeneous landscapes: A strategy for development and application. Rangeland Ecology and Management 62:1-15.

Briggs, JM, Knapp AK, Blair JM, Heisler JL, Hoch GA, Lett MS, and McCarron JK. 2005. An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. BioScience 55:243-254.

Brown JR and Archer S. 1990. Water relations of a perennial grass and seedlings vs adult woody plants in a subtropical savanna, Texas. Oikos 57:366-374.

Brown JR, Blake RR, McPherson GR, and Tate KW. 2005. Rangelands and Global Change. An issue paper created by the Society for Range Management.

Browning DM and Duniway MC. 2011. Digital soil mapping in the absence of field training data: A case study using terrain attributes and semiautomated soil signature derivation to distinguish ecological potential. Applied and Environmental Soil Science Article 2011: article ID 421904. doi:10.1155/2011/421904.

Browning DM, Duniway MC, Laliberte A, and Rango A. 2012. Hierarchical analysis of vegetation dynamics over 71 years: Soil-rainfall interactions in a Chihuahuan desert ecosystem. Ecological Applications (In press).

Browning DM, Laliberte AS, and Rango A. 2011. Temporal dynamics of shrub proliferation: linking shrub patches to landscapes. International Journal of Geographical Information Science 25:913-920.

Buenemann M and Wright J. 2010. Southwest Transformation: Eras of Growth and Land Change in Las Cruces, New Mexico. Southwestern Geographer 14:57-87.

Buffington LC and Herbel CH. 1964. Vegetational changes on a semidesert grassland range from 1858 to 1963. Ecological Monographs 35:139-164.

Burke EJ, Brown SJ, and Christidis N. 2006. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. Journal of Hydrometeorology **7:** 1113-1125.

Carpenter SR, Cole JJ, Pace ML, Batt R, Brock WA, Cline T, Coloso J, Hodgson JR, Kitchell JF, Seekell DA, *et al.* 2011. Early warning signals of regime shifts: a whole ecosystem experiment. Science 332:1079-1082.

Cowie AL, Penman TD, Gorissen L, Winslow MD, Lehmann J, Tyrrell TD, Twomlow S, Wilkes A, Lal R, Jones JW, *et al.* 2011. Towards sustainable land management in the drylands: Scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity. Land degradation and development 22:248-260.

D'Odorico P, Fuentes JD, Pockman WT, Collins SL, He Y,Medeiros JS, DeWekker S, and Litvak ME. 2010. Positive feedback between microclimate and shrub encroachment in the northern Chihuahuan desert. Ecosphere 1:art17. doi:10.1890/ES10-00073.1.

D'Odorico P, Okin GS, and Bestelmeyer BT. 2012. A synthetic review of feedbacks and drivers of shrub encroachment in arid grasslands. Ecohydrology doi:10.1002/eco.259.

Dekker SC, Rietkerk M, and Bierkens MFP. 2007. Coupling microscale vegetation-soil water and macroscale vegetation-precipitation feedbacks in semiarid ecosystems. Global Change Biology 13: 671-678.

Drewa PB, Peters DPC, and Havstad KM. 2006. Population and clonal level responses of a perennial grass following fire in the northern Chihuahuan Desert. Oecologia 150:29-39.

Dugas WA, Hicks RA, and Gibbens RP. 1996. Structure and function of C_3 and C_4 Chihuahuan Desert plant communities: energy balance components. Journal of Arid Environments 34:63-79.

Duniway MC, Bestelmeyer B, and Tugel A. 2010d. Soil processes and properties that distinguish ecological sites and states. Rangelands 32:9-15.

Duniway MC and Herrick JE. 2011. Disentangling road network impacts: the need for a holistic approach. Journal of Soil and Water Conservation 66:31A-36A.

Duniway MC, Herrick JE, and Monger HC. 2007. The high water-holding capacity of petrocalcic horizons. Soil Science Society of American Journal 71:812-819.

Duniway MC, Herrick JE, and Monger HC. 2010a. Spatial and temporal variability of plant-available water in calcium carbonate-cemented soils and consequences for arid ecosystem resilience. Oecologia 163:215-226.

Duniway MC, Herrick JE, Pyke DA, and Toledo DP. 2010b. Assessing transportation infrastructure impacts on rangelands: test of a standard rangeland protocol. Rangeland Ecology and Management 63:524-536.

Duniway MC, Snyder KA, and Herrick JE. 2010c. Spatial and temporal patterns of water availability in a grass-shrub ecotone and implications for grassland recovery in arid environments. Ecohydrology 3:55-67.

Duval BD and Whitford WG. 2008. Resource regulation by a twig-girdling beetle has implications for desertification. Ecological Entomology 33:161-166.

Eldridge DJ and Whitford WG. 2009. Soil disturbance by native animals along grazing gradients in an arid grassland. Journal of Arid Environments 73:1144-48.

Eldridge DJ, Whitford WG, and Duval BD. 2009. Animal disturbances promote shrub maintenance in a desertified grassland. Journal of Ecology 97:1302-10.

Eltahir EAB. 1998. A soil moisture-rainfall feedback mechanism. 1: Theory and observations. Water Resources Research 34:765-777.

Ernest SKM, Brown JH, Thibault KM, White EP, and Goheen JR. 2008. Zero sum, the niche, and metacommunities: long-term dynamics of community assembly. American Naturalist 172:E257-269.

Ernest SKM, Malone TJ, and Brown JH. 2009. Long-term monitoring and experimental manipulation of a Chihuahuan Desert ecosystem near Portal, Arizona, USA. Ecology 90:1708.

Estell RE, Fredrickson EL, and Peters DPC. 2006. Introduction to special issue - Landscape linkages and cross scale interactions in arid and semiarid ecosystems. Journal of Arid Environments 65:193-195.

Estes JA, Terborgh J, Brashares JS, Power, ME, Berger J, Bond WJ, Carpenter SR, Essington TE, Holt RD, Jackson JBC, *et al.* 2011. Trophic downgrading of planet earth. Science 333:301-306.

Evans, SE, Byrne KM, Lauenroth WK, and Burke IC. 2011. Defining the limit to resistance in a drought-tolerant grassland: long-term severe drought significantly reduces the dominant species and increases ruderals. Journal of Ecology 99:1500-1507.

Fredrickson EL, Estell RE, Laliberte AS, and Anderson DM. 2006. Mesquite recruitment in the Chihuahuan Desert: historic and prehistoric patterns with long-term impacts. Journal of Arid Environments. 65:285-295.

Fredrickson EL, Havstad KM, Estell R, and Hyder P. 1998. Perspectives on desertification: south-western United States. Journal of Arid Environments 39: 191-207.

Geist HJ and Lambin EF. 2004. Dynamic causal patterns of desertification. BioScience 54:817-829.

Gentner BJ and Tanaka JA. 2002. Classifying federal public land grazing permittees. Journal of Range Management 55:2-11.

Gibbens RP, McNeely RP, Havstad KM, Beck RF, and Nolen B. 2005. Vegetation changes in the Jornada Basin from 1858 to 1998. Journal of Arid Environments 61:651-668.

Gile LH, Monger HC, Grossman RB, Ahrens RJ, Hawley JW, Peterson FF, Gibbons RP, Lenz JM, Bestelmeyer BT, and Nolen BA. 2007. A 50th anniversary guidebook for the Desert Project. USDA National Soil Survey Center, Lincoln, Nebraska, USA.

Gillette D and Monger CH. 2006. Eolian processes across the Jornada basin. In: Havstad K, Huenneke LF, and Schlesinger WH (Eds). Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin Long Term Ecological Research site. Oxford University Press, New York, NY.

Gillette DA and Pitchford AM. 2004. Sand flux in the northern Chihuahuan desert, New Mexico, USA, and the influence of mesquite-dominated landscapes. Journal of Geophysical Research 109: F04003, doi:10.1029/2003JF000031.

Grimm NB, Faeth SH, Golubiewski NE, Redman CL, Wu J, Bai X, and Briggs JM. 2008b. Global change and the ecology of cities. Science 319:756-760.

Grimm NB, Foster D, Groffman PM, Grove JM, Hopkinson CS, Nadelhoffer K, Pataki DE and Peters DPC. 2008a. Land change: ecosystem responses to urbanization and pollution across climatic and societal gradients. Frontiers in Ecology and the Environment 5:264-272.

Grover HD and Musick HB. 1990. Shrubland encroachment in Southern New Mexico, U.S.A.: an analysis of desertification processes in the American Southwest. Climate Change 17:305-330.

Gutiérrez-Jurado HA, Vivoni ER, Istanbulluoglu E and Bras RL. 2007. Ecohydrological response to a geomorphically significant flood event in a semiarid catchment with contrasting ecosystems. Geophysical Research Letters 34: L24S25, doi:10.1029/2007GL030994.

Hallmark CT and Allen BL. 1975. The distribution of creosotebush in west Texas and eastern New Mexico as affected by selected soil properties. Soil Science Society American Proceedings 39:120-124.

Harper W and Skaggs RK. 1999. Predicting Land Purchase Preferences Using Farmland Preservation Attitudes. Forum of the Association for Arid Land Studies XV:46-53.

Havstad KM, Huenneke LF, and Schlesinger WH (Eds). 2006. Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin Long Term Ecological Research site. Oxford University Press, New York, NY.

Havstad KM, Peters DPC, Skaggs R, Brown JR, Bestelmeyer BT, Fredrickson E, Herrick JE, and Wright J. 2007. Ecosystem services to and from rangelands of the western US. Ecological Economics 64:261-268.

Herrick JE, Havstad KM, and Rango A. 2006. Remediation Research in the Jornada Basin: Past and Future. In: Havstad K, Huenneke LF, and Schlesinger WH (Eds). Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin Long Term Ecological Research site. Oxford University Press, New York, NY.

Herrick JE, Lessard VC, Spaeth KE, Shaver PL, Dayton RS, Pyke DA, Jolley L, and Goebel JJ. 2010. National ecosystem assessments supported by local and scientific knowledge. Frontiers in Ecology and the Environment 8:403–408.

Herrick JE, Van Zee JW, Havstad KM, Burkett LM, and Whitford WG. 2005. Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems. The University of Arizona Press, Tucson, AZ.

Hestir KL. 2011. Land cover classification and change detection in drylands: an evaluation of remote sensing approaches. Master's thesis. New Mexico State University, Las Cruces, NM.

Ho MC, Roisman RE, and Virginia RA. 1996. Using strontium and rubidium tracers to characterize nutrient uptake patterns in creosotebush and mesquite. Southwestern Naturalist 41:239-247.

Holmgren M and Scheffer M. 2001. El Niño as a window of opportunity for the restoration of degraded arid ecosystems. Ecosystems 4:151-59.

Humphrey RR. 1958. The desert grassland a history of vegetational change and an analysis of causes. Botanical Review 24:193-252.

Huxman TE, Smith MD, Fay PA, Knapp AK, Shaw MR, Loik ME, Smith SD, Tissue DT, Zak JC, Weltzin JF, *et al.* 2004. Convergence across biomes to a common rain-use efficiency. Nature 429:651-654.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: The Physical Science Basis. In: Solomon S, Qin D, and Manning M (Eds). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Ivanov VY, Bras RL, and Vivoni ER. 2008. Vegetation-hydrology dynamics in complex terrain of semiarid areas. II. Energy-water controls of vegetation spatiotemporal dynamics and topographic niches of favorability. Water Resources Research 44: W03430, doi:10.1029/2006WR005595.

James AI, Edridge DJ, Koen TB, and Whitford WG. 2008. Landscape position moderates how ant nests affect hydrology and soil chemsitry across a Chihuahuan Desert watershed. Landscape Ecology 23:961-975.

Karl TR and Wright RW. 1998. Secular trends of precipitation amount, frequency, and intensity in the United States. Bulletin American Meteorological Society 79**:**231-241.

Kéfi S, Rietkerk M, Alados CL, Pueyo Y, Papanastasis VP, ElAich A and de Ruiter PC. 2007. Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. Nature 449: 213-217.

Kerley GIH, and Whitford WG. 2009. Can kangaroo rat graminivory contribute to the persistence of desertified shrublands? Journal of Arid Environments 73: 651–657.

Knapp A, Briggs J, Blair J, and Turner CL. 1998. Patterns and controls of aboveground net primary production in tallgrass prairie. In: Knapp A, Briggs J, Hartnett J, and Collins SL (Eds). Grassland dynamics: Long-term ecological research in tallgrass prairie. Oxford University Press, New York, NY.

Kofinas G, Sayre NF, J. Harrington, Pontius R, *et al.* In prep. Maps and locals: An experiment in integrating spatial analysis and local knowledge across LTER sites to study the dynamics of social-ecological systems.

Kraimer RA, and Monger HC. 2009. Carbon isotopic subsets of soil carbonate -- a particle-size comparison of limestone and igneous parent materials. Geoderma 150:1-9.

Kurc SA and Small EE. 2004. Dynamics of evapotranspiration in semiarid grassland and shrubland ecosystems during the summer monsoon season, central New Mexico. Water Resources Research 40:W09305, doi: 10.1029/2004WR003068.

Kutner M, Nachtsheim C, Neter J, and Li W. 2005. Applied linear statistical models (5th ed.). McGraw-Hill/Irwin. Boston, MA.

Laliberte AS, Fredrickson EL, and Rango A. 2007. Combining decision trees with hierarchical object-oriented image analysis for mapping arid rangelands. Photogrammetric Engineering and Remote Sensing 73:197-207.

Laliberte AS, Goforth MA, Steele CM, and Rango A. 2011. Multispectral remote sensing from unmanned aircraft: image processing workflows and applications for rangeland environments. Remote Sensing 3:2529-2551.

Laliberte AS, Herrick JE, and Rango A. 2010. Acquisition, orthorectification, and object-based classification of unmanned aerial vehicle (UAV) imagery for rangeland monitoring. Photogrammetric Engineering and Remote Sensing 76:661-772.

Lauenroth WK and Sala OE. 1992. Long-term forage production of North American shortgrass steppe. Ecological Applications 2:397-403.

Lauenroth WK, Sala OE, Coffin DP, and Kirchner TB. 1994. The importance of soil water in the recruitment of *Bouteloua gracilis* in the shortgrass steppe. Ecological Applications 4:741-749.

Li J, Okin GS, Alvarez L, and Epstein HE. 2008. Effects of wind erosion on the spatial heterogeneity of soil nutrients in two desert grassland communities. Biogeochemistry 88:73-88.

Li J, Okin GS, Alvarez LJ, and Epstein HE. 2009a. Sediment deposition and soil nutrient heterogeneity in two desert grassland ecosystems, southern New Mexico. Plant and Soil 319:67-84.

Li J, Okin GS, and Epstein HE. 2009b. Effects of enhanced wind erosion on surface soil texture and characteristics of windblown sediments. Journal of Geophysical Research-Biogeosciences DOI:10.1029/2008JG000903.

Li J, Okin GS, Hartman LJ, and Epstein HE. 2007. Quantitative assessment of wind erosion and soil nutrient loss in desert grasslands of southern New Mexico, USA. Biogeochemistry 85:317-332.

Liffmann RH, Huntsinger L, and Forero LC. 2000. To ranch or not to ranch: Home on the urban range? Journal of Range Management 53: 362-370.

Lightfoot DC, Brantley SL, and Allen CD. 2008. Geographic patterns of ground-dwelling arthropods across an ecoregional transition in the North American Southwest. Western North American Naturalist 68: 83-102.

Liu X, Monger HC, and Whitford WC. 2007. Calcium carbonate in termite galleries: biomineralization or upward transport? Biogeochemistry 82: 241-250.

Mabry TJ, Hunziker JH, and Difeo DR (Eds). 1977. Creosote bush: Biology and chemistry of Larrea in new world deserts. Dowden, Hutchinson and Ross, Stroudsburg, PA.

Mau-Crimmins TM, Schussman HR, and Geiger EL. 2006. Can the invaded range of a species be predicted sufficiently using only native-range data?: Lehmann lovegrass (*Eragrostis lehmanniana*) in the southwestern United States. Ecological Modelling 193:736-746.

McGee KP and Marshall DL. 1993. Effects of variable moisture availability on seed germination in three populations of *Larrea tridentata*. American Midland Naturalist 130:75-82.

McGlone CM and Huenneke LF. 2004. The impact of a prescribed burn on introduced Lehmann lovegrass versus native vegetation in the northern Chihuahuan Desert. Journal of Arid Environments 57:297-310.

MEA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: desertification synthesis. World Resources Institute, Washington, DC.

Méndez-Barroso LA and Vivoni ER. 2010. Inferring a vegetation-rainfall feedback mechanism from remote sensing and ground observations in the Rio Sonora basin. Journal of Arid Environments 74:549-555.

Meserve PL, Kelt DA, Milstead WB, and Gutierrez JR. 2003. Thirteen Years of Shifting Top-Down and Bottom-Up Control. BioScience 53:633-646.

Minnick TJ and Coffin DP. 1999. Geographic patterns of simulated establishment of two *Bouteloua* species: Implications for distributions of dominants and ecotones. Journal of Vegetation Science 10:343-356.

Monger HC. 2006. Soil development in the Jornada Basin. In: Havstad K, Huenneke LF, and Schlesinger WH (Eds). Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin Long Term Ecological Research site. Oxford University Press, New York, NY.

Monger HC and Bestelmeyer BT. 2006. The soil-geomorphic template and biotic change in arid and semi-arid ecosystems. Journal of Arid Environments 65:207-218.

Monger HC, Cole DR, Buck BJ, and Gallegos RA. 2009a. Scale and the isotopic record of C_4 plants in pedogenic carbonate: from the biome to the rhizosphere. Ecology 90:1498-1511.

Monger HC, Gile LH, Hawley JW, and Grossman RB. 2009b. The Desert Project--An analysis of aridland soil-geomorphic processes. New Mexico Agricultural Experimental Station, Bulletin 798.

Monger HC, Mack GH, Nolen BA, and Gile LH. 2006. Regional setting of the Jornada LTER. In: Havstad K, Huenneke LF, and Schlesinger WH (Eds). Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin Long Term Ecological Research site. Oxford University Press, New York, NY.

Monger HC, Southard RJ, and Boettinger JL. 2011. Aridisols. In: Huang PM, Li Y, and Sumner ME (Eds.). Handbook of soil sciences: properties and processes (2nd ed.). CRC Press.

Moran MS, Peters DPC, McClaran M, Nichols MH, and Adams M. 2008. Long-term data collection at USDA experimental sites for studies of ecohydrology. Ecohydrology 1:377-393.

Musick HB. 1978. Phosphorus toxicity in seedlings of *Larrea divaricata* grown in solution culture. Botanical Gazette 139:108-111.

Nord M and Cromartie J. 1999. Rural areas attract young families and college graduates. Rural Conditions and Trends 9:28-34.

Okin GS. 2008. A new model of wind erosion in the presence of vegetation. Journal of Geophysical Research 113:F02S10, doi:10.1029/2007JF000758.

Okin GS, and Gillette DA. 2001. Distribution of vegetation in wind-dominated landscapes: implications for wind erosion modeling and landscape processes. Journal of Geophysical Research 106:9673-9683.

Okin GS, D'Odorico P, and Archer SR. 2009a. Impacts of feedbacks on Chihuahuan Desert grasslands: transience and metastability driven by grass recruitment. Journal of Geophysical Research 114:G01004. doi:10.1029/2008JG000833.

Okin GS, Herrick JE, and Gillette DA. 2006. Multiscale controls on and consequences of aeolian processes in landscape change in arid and semiarid environments. Journal of Arid Environments 65:253-275.

Okin GS, Parsons AJ, Wainwright J, Herrick JE, Bestelmeyer BT, and Peters DPC. 2009b. Does connectivity explain desertification? BioScience 59:237-244.

Parton WJ. 1978. Abiotic section of ELM. In: Innis, G.S., (Ed.), Grassland simulation model. Ecological Studies Volume 26. Springer Verlag, New York, NY, USA, pp 31-53.

Peinetti HR, Fredrickson EL, Peters DPC, Cibils AF, Roacho-Estrada JO, and Laliberte A. 2011. Foraging behavior of heritage versus recently introduced herbivores on desert landscapes of the American Southwest. Ecosphere 2: 1-14.

Peters DPC. 2000. Climatic variation and simulated patterns in seedling establishment of two dominant grasses at a semi-arid and grassland ecotone. Journal of Vegetation Science 11:493-504.

Peters DPC. 2002. Plant species dominance at a grassland-shrubland ecotone: An individual-based gap dynamics model of herbaceous and woody species. Ecological Modelling 152:5-32.

Peters DPC. 2010. Accessible ecology: synthesis of the long, deep, and broad. Trends in Ecology and Evolution 25: 592-601.

Peters DPC. 2011. Globalization: Ecological consequences of global-scale connectivity in people, resources, and information. Pp 201-222 in The Systemic Dimension of Globalization. P. Pachura, ed. ISBN 978-953-307-384-2. Intech Open Access Publishers (www.intechopen.com).

Peters DPC, Bestelmeyer, BT, Herrick JE, Monger HC, Fredrickson EL, and Havstad KM. 2006. Disentangling complex landscapes: new insights to forecasting arid and semiarid system dynamics. BioScience 56:491-501.

Peters DPC, Bestelmeyer BT, and Turner MG. 2007. Cross-scale interactions and changing pattern-process relationships: consequences for system dynamics. Ecosystems 10:790-796.

Peters DPC, Groffman PM, Nadelhoffer KJ, Grimm NB, Collins SL, Michener WK, and Huston MA. 2008. Living in an increasingly connected world: a framework for continental-scale environmental science. Frontiers in Ecology and the Environment 5:229-237.

Peters DPC, Herrick JE, Monger HC, and Huang H. 2010. Soil-vegetation-climate interactions in arid landscapes: effects of the North American monsoon on grass recruitment. Journal of Arid Environments 74: 618-623.

Peters DPC, Herrick JE, Okin GS, Pillsbury F, Duniway M, Vivoni ER, Sala OE, Havstad KM, Monger HC, Yao J, Anderson J. 2011a. Modifying patch-scale connectivity to initiate landscape change: an experimental approach to link scales. American Geophysical Union Fall meeting. San Francisco, CA.

Peters DPC, Laney CM, Lugo AE, Collins SL, Driscoll CT, Groffman PM, Grove JM, Knapp AK, Kratz TK, Ohman MD, *et al.* 2012a. Long-term trends in ecological systems: a basis for understanding responses to global change. USDA Agricultural Research Service Publication No. XX. Washington, D. C.

Peters DPC, Lugo AE, Chapin FS III, Pickett STA, Duniway M, Rocha AV, Swanson FJ, Laney C, and Jones J. 2011b. Cross-system comparisons elucidate disturbance complexities and generalities. Ecosphere 2:art81. doi:10.1890/ES11-00115.1

Peters DCP, Pielke RA, Bestelmeyer BT, Allen CD, Munson-McGee S, and Havstad KM. 2004a. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proceedings of the National Academy of Sciences 101:15130-15135.

Peters DPC, Urban DL, Gardner RH, Breshears DD, and Herrick JE. 2004b. Strategies for ecological extrapolation. Oikos 106:627-636.

Peters DPC and Yao J. 2012. Long-term experimental loss of foundation species: consequences for dynamics at ecotones across heterogeneous landscapes. Ecosphere (in press).

Peters DPC, Yao J, Browning D, and Rango A. Submitted. Regime shift reversal under directional climate change: the role of sequential processes and early indicators. Ecology.

Peters DPC, Yao J, Sala OE, and Anderson J. 2012b. Directional climate change and potential reversal of desertification in arid and semiarid ecosystems. Global Change Biology 18:151-163.

Peterson GD, Beard D, Beisner B, Beisner BE, Bennett EM, Carpenter SR, Cumming GS, Dent CL, and Havlicek TD. 2003. Assessing future ecosystem services: a case study of the northern highland lake district, Wisconsin. Conservation Ecology **7**:1. [online] URL: http://www.consecol.org/vol7/iss3/art1/

Pierini NA, Templeton RC, Robles-Morua A, and Vivoni ER. 2011. Sonoran desert vegetation shifts and watershed-scale ecohydrological dynamics during the North-American monsoon. American Geophysical Union Fall Meeting, San Francisco, CA.

Rango A, Havstad KM, and Estell RE. 2011. The utilization of historical data and geospatial technology advances at the Jornada Experimental Range to support western America ranching culture. Remote Sensing 3:2089-2109.

Rango A, Laliberte AS, Herrick JE, Winters C, Havstad KM, Steele C, and Browning DM. 2009. UAV-based remote sensing for rangeland assessment, monitoring, and management. Journal of Applied Remote Sensing 3:033542.

Rango A, Laliberte AS, Steele C, Herrick JE, Bestelmeyer BT, Schmugge T, Roanhorse A, and Jenkins V. 2006. Using unmanned vehicles for rangelands: current applications and future potentials. Environmental Practice 8:159-168.

Rasmussen K, Fog B, and Madsen JE. 2001. Desertification in reverse? Observations from northern Burkina Faso. Global Environmental Change 11:271–282.

Rastetter EB, Aber JD, Peters DPC, Ojima DS, and Burke IC. 2003. Using mechanistic models to scale ecological processes across space and time. BioScience 53:1-9.

Ravi S, D'Odorico P, and Okin GS. 2007. Hydrologic and aeolian controls on vegetation patterns in arid landscapes. Geophysical Research Letters 34: L24S23; 10.1029/2007GL031023.

Ravi S, D'Odorico P, Wang L, and Collins S. 2008. Form and function of grass ring patterns in arid grasslands: the role of abiotic controls. Oecologia 158:545-555.

Reichmann L, Sala O, Gherardi L, and Peters DPC. 2011. Non-linear ecosystem response to long-term changes in precipitation and nitrogen availability in a desert grassland. 96th Annual Meeting, Ecological Society of America, Austin, TX.

Reynolds JF, Kemp PR, Ogle K, and Fernandez RJ. 2004. Modifying the 'pulse–reserve' paradigm for deserts of North America: precipitation pulses, soil water, and plant responses. Oecologia 141:194-210.

Reynolds JF and Stafford Smith DM. 2002. Global desertification: do humans cause deserts? Dahlem University Press, Berlin.

Reynolds JF, Stafford Smith DM, Lambin EF, Turner BL II, Mortimore M, Batterbury SPJ, Downing TE, Dowlatabadi H, Fernandez RJ, Herrick JE, *et al.* 2007. Global desertification: building a science for dryland development. Science 316: 847-851.

Reynolds JF, Virginia RA, Kemp PR, de Soyza AG, and Tremmel DC. 1999. Impact of drought on desert shrubs: Effects of seasonality and degree of resource island development. Ecological Monographs 69:69-106.

Riebsame WE. 1997. Atlas of the New West: portrait of a changing nation. W.W. Norton Co., New York.

Rietkerk M, Boerlijst MC, van Langevelde F, HilleRisLambers R, van de Koppel J, Kumar L, Prins HHT, and de Roos AM. 2002. Self-Organization of vegetation in arid ecosystems. The American Naturalist 160: 524-530.

Rietkerk M, Van den Bosch F and Van de Koppel J. 1997. Site-specific properties and irreversible vegetation changes in semi-arid grazing systems. Oikos 80:241-252.

Rios-Casanova L and Bestelmeyer BT. 2008. What can ant diversity-energy relationships tell us about land use and land change (Hymenoptera: Formicidae)? Myrmecological News 11: 183-90.

Roth GA, Steinberger Y, and Whitford WG. 2009. Small mammal herbivory: Feedbacks that help maintain desertified ecosystems. Journal of Arid Environments 73:62-65.

Roth GA, Whitford WG, and Steinberger Y. 2007. Jackrabbit (*Lepus californicus*) herbivory changes dominance in desertified Chihuahuan Desert ecosystems. Journal of Arid Environments 70:418-426.

Rowcliffe JM, Field J, Turvey ST, and Carbone C. 2008. Estimating animal density using camera traps without the need for individual recognition. Journal of Applied Ecology 45:1228-1236.

Ryan M, Archer S, *et al*. 2008. Land resources: forests and arid lands. In: Backlund P, Janetos A, Schimel D, *et al.* (Eds). The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A Report by the US Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC USA.

Sala OE, Meyerson LA, and Parmesan C (Eds). 2009. Biodiversity change and human health: From ecosystem services to spread of disease. Island Press, Washington DC.

Sala OE, van Vuuren D, Pereira HM, *et al.* 2006. Biodiversity across scenarios. In: Millennium Ecosystem Assessment Board, Ecosystems and human well-being: Scenarios. Island Press. (http://www.millenniumassessment.org/).

Sayre NF. 2011. A History of Land Use and Natural Resources in the Middle San Pedro Valley, Arizona. Journal of the Southwest 53: 87-137.

Scheffer M, Bascompte J, Brock WA, Brovkin V, Carpenter SR, Dakos V, Held H, van Nes EH, Rietkerk M and Sugihara G. 2009. Early-warning signals for critical transitions. Nature 461:53-59.

Scheffer M, Carpenter S, Foley JA, Folke C, and Walker B. 2001. Catastrophic shifts in ecosystems. Nature 413:591-596.

Schlesinger WH, Reynolds JF, Cunningham GL, Huenneke LF, Jarrell WM, Virginia RA, and Whitford WG. 1990. Biological feedbacks in global desertification. Science 247:1043-1048.

Scholes R J and Archer SR. 1997. Tree-grass interactions in savannas. Annual Review of Ecology and Systematics 28:517-544.

Schussman H, Geiger E, Mau-Crimmins T, and Ward J. 2006. Spread and current potential distribution of an alien grass, *Eragrostis lehmanniana* Nees, in the southwestern USA: comparing historical data and ecological niche models. Diversity and Distributions 12:582-592.

Seager R, Ting MF, Held I, Kushnir Y, Lu J, Vecchi G, Huang H, Harnik N, Leetmaa A, Lau N, *et al.* 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181-1184.

Simpson BB (Ed). 1977. Mesquite: its biology in two desert scrub ecosystems. Halstead Press, New York, NY.

Skaggs RK, Edwards Z, Bestelmeyer BT, Wright JB, Williamson J, and Smith P. 2011. Vegetation maps at the passage of the Taylor Grazing Act (1934): a baseline to evaluate rangeland change after a regime shift. Rangelands 33:13-19.

Skaggs RK and VanLeeuwen DM. 2004. New Mexicans' attitudes toward the environment, agriculture and government. Agricultural Experiment Station Research Bulletin #786, New Mexico State University.

Suding KN and Hobbs RJ. 2009. Threshold models in restoration and conservation: a developing framework. Trends in Ecology & Evolution 24:271-279.

Templeton RC. 2011. Insights on seasonal fluxes in a desert shrubland watershed from a distributed sensor network. M.S. Thesis, Arizona State University, Tempe, AZ.

Templeton RC, Vivoni ER, Mendez-Barroso LA, Rango A, Laliberte A, and Saripallis S. 2010. Emerging technologies for ecohydrological studies during the North American monsoon in a Chihuahuan Desert watershed. American Geophysical Union Fall Meeting, San Francisco, CA.

Throop HL and Archer SR. 2007. Interrelationships among shrub encroachment, land management, and litter decomposition in a semidesert grassland. Ecological Applications 17:1809–1823.

Throop HL and Archer SR. 2009. Resolving the dryland decomposition conundrum: some new perspectives on potential drivers. Progress in Botany 70:171-194.

Throop HL, Reichmann LG, Sala OE, and Archer SR. 2012. Response of dominant grass and shrub species to water manipulation: An ecophysiological basis for shrub invasion in a Chihuahuan Desert grassland. Oecologia DOI: 10.1007/s00442-011-2217-4.

Tiedemann AR and Klemmedson JO. 1973. Nutrient availability in desert grassland soils under mesquite (*Prosopis juliflora*) trees and adjacent open areas. Soil Science Society of America Journal 37: 107-110.

Torell LA, Rimbey NR, Ramirez OA, *et al.* 2005. Income earning potential versus consumptive amenities in determining ranchland values. Journal of Agricultural and Resource Economics 30:537-560.

Travis WR. 2007. New geographies of the American West: land use and the changing patterns of place. Island Press. Washington, DC.

Turnbull L, Wilcox BP, Belnap J, Ravi S, D'Odorico P, Childers D, Gwenzi W, Okin G, Wainwright J, Caylor KK, *et al.* 2011. Understanding the role of ecohydrological feedbacks in ecosystem state change in drylands. Ecohydrology. doi: 10.1002/eco.265.

Van de Koppel J, Rietkerk M, and Weissing FJ. 1997. Catastrophic vegetation shifts and soil degradation in terrestrial grazing systems. Trends in Ecology & Evolution 12:352-356.

Van Devender TR. 1995. Desert grassland history: changing climates, evolution, biogeography, and community dynamics. In: McClaran MP and Van Devender TR (Eds). The desert grassland. The University of Arizona, Tucson, AZ.

Vivoni ER. 2011. Diagnosing seasonal vegetation impacts on evapotranspiration and its partitioning at the catchment scale during SMEX04-NAME. Journal of Hydrometeorology (In Review).

Vivoni, ER. 2012. Spatial patterns, processes and predictions in ecohydrology: integrating technologies to meet the challenge. Ecohydrology. DOI: 10.1002/eco.1248 (In Press).

Vivoni ER, Entekhabi D, Bras RL, Ivanov VY. 2007. Controls on runoff generation and scale-dependence in a distributed hydrologic model. Hydrology and Earth System Sciences 11:1683-1701.

Vivoni ER, Rodriguez JC and Watts CJ. 2010. On the spatiotemporal variability of soil moisture and evapotranspiration in a mountainous basin within the North American monsoon region. Water Resources Research 46: W02509, doi:10.1029/2009WR008240.

Vivoni ER, Tai K and Gochis DJ. 2009. Effects of initial soil moisture on rainfall generation and subsequent hydrologic response during the North American monsoon. Journal of Hydrometeorology 10:644-664.

Wainwright J, Parsons AJ, Schlesinger WH, and Abrahams AD. 2002. Hydrology-vegetation interactions in areas of discontinuous flow on a semi-arid bajada, Southern New Mexico. Journal of Arid Environments 51:319-338.

Walker BH, Ludwig D, Holling CS, and Peterman RM. 1981. Stability of semi-arid savanna grazing systems. Journal of Ecology 69: 473-498.

Weems SL and Monger HC. 2012. Banded vegetation-dune formation in the Medieval Warm Period and 20th Century, Chihuahuan Desert, New Mexico, USA. Ecosphere. (In press).

Whitford WG, Barness G, and Steinberger Y. 2008. Effects of three species of Chihuahuan Desert ants on annual plants and soil properties. Journal of Arid Environments 72:392-400.

Whitford WG and Bestelmeyer BT. 2006. Chihuahuan Desert fauna: effects on ecosystem properties and processes. In: Havstad KM, Huenneke LF, Schlesinger WH (Eds). Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin long-term ecological research site. Oxford University Press, New York, NY.

Whitford WG, Ginzburg O, Berg N, and Steinberger Y. 2012 Do long-lived ants affect soil microbial communities? Biology and Fertility of Soils. DOI: 10.1007/s00374-011-0619-4.

Whitford WG and Steinberger Y. 2010. Pack rats (*Neotoma* spp.): Keystone ecological engineers? Journal of Arid Environments 74:1450-1455.

Wierenga PJ, Hendrickx JMH, Nash MH, Ludwig J, and Daugherty LA. 1987. Variation of soil and vegetation with distance along a transect in the Chihuahuan Desert. Journal of Arid Environments 13:53-63.

Wilcox BP, Turnbull L, Young MH, Williams CJ, Ravi S, Seyfried MS, Bowling DR, Scott RL, Germino MJ, Caldwell TG, *et al.* 2011. Invasion of shrubland by exotic grasses: ecohydrological sequences in cold versus warm deserts. Ecohydrology. doi: 10.1002/eco.247.

Williams A, Robins C, Buck BJ, and Monger HC. 2008. Common ground: discovering a shared purpose in Inner Mongolia. Soil Survey Horizons 49:96-97.

Williamson, J, Bestelmeyer BT, and Peters DPC. 2012. Spatiotemporal patterns of production can be used to detect state change across an arid landscape. Ecosystems (in press).

Wondzell SM, Cunningham GL, and Dominique B. 1996. Relationships between landforms, geomorphic processes, and plant communities on a watershed in the northern Chihuahuan Desert. Landscape Ecology 11:351-362.

Wood L. 2003. The Ranchers of New Mexico: A Portrait. Master's thesis. New Mexico State University, Las Cruces, NM.

Woodhouse CA, Meko DM, MacDonald GM, Stahle DW, and Cook ER. 2010. A 1200-year perspective of 21st century drought in southwestern North America. Proceedings of the National Academy of Sciences of the United States of America 107: 21283-21288.

Woods S, Archer S, and Schwinning S. 2011. Early taproot development of a xeric shrub (*Larrea tridentata*) is optimized within a narrow range of soil moisture. Plant Ecology 212:507-517.

Wooton EO. 1908. The range problem in New Mexico. New Mexico Agricultural Experiment Station, Bulletin 66.

Yahdjian L and Sala OE. 2002. A rainout shelter design for intercepting different amounts of rainfall. Oecologia 133:95-101.

Yahdjian L, Sala OE, and Austin AT. 2006. Differential controls of water input on litter decomposition and nitrogen dynamics in the Patagonian Steppe. Ecosystems 9:128-141.

SUPPLEMENTARY DOCUMENTS

Data management plan

The Jornada Information Management System (JIMS) provides the infrastructure for the curation, protection, access, and analysis of Jornada LTER (JRN) data holdings. Our mission is to protect and provide access to publically funded research data, tools, and findings that result from JRN research and associated collaborations. The purpose of our information management system is to provide protocols and services for data collection, verification, organization, archive, and distribution. One of the primary tools to insuring long-term usefulness of data and products is detailed metadata that describes the research project and its related datasets. Metadata are shared and leveraged amongst services and tools of the JIMS. We provide access to hundreds of data sets linked directly to our program or from other research locations and management agencies in support of multi-user needs. Our intent is to provide data sets, science-based information, tools, and technologies that can be used, through simple or more complex analyses, to address the needs of a diverse user community. JIMS is a multi-organization system that contains data and metadata holdings and ancillary information from the Jornada through the LTER, USDA, and AISE as well as collaborative efforts, either through data collection and storage for other sites (e.g., BLM-Malpais Borderlands) or through development of tools to improve data access and analysis (e.g., EcoTrends: http://www.ecotrends.info; The Nature Conservancy Landscape Toolbox: http://www.landscapetoolbox.org/).

A. Information management system. Our system consists of six major components: (a) data management implementation/process, (b) management of data, spatial maps, and imagery, and the creation of and access to associated metadata, (c) formal data management protocols, (d) tools and resources dedicated to harvest, document, archive, manage, and make data accessible, and tools to access, analyze, and download the data and metadata, (e) networking and computing services, and (f) support staff.

(a) Data management implementation. Our site manager, John Anderson, acts as the liaison between researchers and the information management team. His involvement begins during the Project Design phase with the completion of the Jornada Notification of Research form by a researcher prior to the start of work. This form alerts the Information Manager (IM) to the new study and potential LTER data sets. Upon initiation of a new study, the researcher completes a Project Documentation form that provides the second level of "metadata" documentation, and arranges for GPS of the data collection sites by the LTER field crew. Research related forms can be found at http://jornada-www.nmsu.edu/site/dm/readme.php.

In the data collection phase, the IM helps researchers to design field and laboratory data sheets that facilitate data entry and analysis. The investigator completes a Data Set Documentation form to provide the metadata that fully describe the data set. Both Project and Data Set Documentation forms are provided with the data set when it is requested or obtained from our website. JIMS data entry programs validate data upon entry. Computer files are subjected to further verification by graphing and/or error-checking programs, and/or examination by the responsible investigator. Final quality assurance rests with the investigator who submits data for inclusion in the Data Management System. Direct communication between researchers and the IM ensures the timely submission and accessibility of data, as required by NSF guidelines.

One of the biggest challenges is migrating historic and current data into formats consistent with database rules, and to support geospatial analysis and mapping. Processing data files that have been collected or designed without database protocols is an enormous workload. Our approach that focuses on continued interactions between researchers and the IM minimizes this workload (Fig. C1).

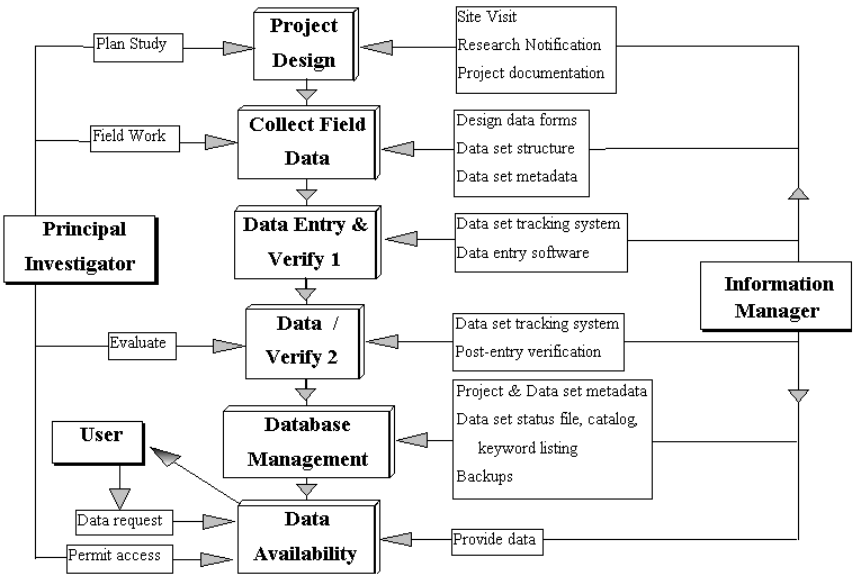

Figure C1

(b) Management of data and metadata. We employ many tools in this system, including SQL Server, GIS Server, geodatabases, Drupal, data entry systems, and open-source geoportals. See the section "Website, Data Catalog, and Geoportals" under (d) for an explanation of Drupal and geoportals. We are building a system that optimizes the contribution of each tool to the total system. We also optimize the roles of people on the IM team as the system evolves. We are building, and have pilot tested, an approach to information management that integrates tabular research data with the spatial component of data sample location as a complete dataset package. This approach allows us to easily integrate data from more than one research program or project, and facilitates the research described in Sections 1 and 2.

(c) Data protocols and metadata standards. Procedures are conducted in accordance with recommendations and guidelines developed by the LTER Network-Level Information Managers Committee (IMC). Data access, acknowledgement, and data management policies can be found at http://jornada-www.nmsu.edu/jrndmpol.php. A full description of our information management system is available at http://jornada-www.nmsu.edu/informationmanagement.php. JRN data policies are in accordance with those developed by the LTER IMC (http://www.lternet.edu/data/netpolicy.html). Compliant EML is being produced for each dataset before being harvested into the LTER Data Portal.

(d) Tools and resources dedicated to harvest, document, archive, manage, and make data accessible.

Data derived from LTER funding are made freely and publicly available within 2 years after collection (see Suppl. Table A1). Data are routinely updated online, typically within one day after received by the IM. Data are designated as either "Unrestricted" and available online or "Restricted" with release authority by the responsible investigator. Restricted datasets are those in preparation for publication or part of student research that is protected to allow them the opportunity to publish. A listing of restricted datasets and associated justifications, as approved by the JRN Executive Committee, is available at http://jornada-www.nmsu.edu/restricteddatasets.php.

Our website offers options for users to access, query, and understand the datasets online before deciding to download. We will continue to add data accessibility and analytical tool capabilities as they are made available from our collaborative projects (EcoTrends, Landscape Toolbox). Datasets are delivered to users as downloadable dataset packages from the data catalogs and geoportals through web queries. The dataset package includes metadata files, data files (with coordinates for each data record), and a shapefile (spatial representation of dataset location). We plan to have all long-term JRN LTER datasets in this system by the end of May 2012 (see Suppl. Table A1). These datasets are currently available online at http://jornada-www.nmsu.edu/datacat.php, and a listing is available at http://jornada-www.nmsu.edu/longtermdatasets.php. The data table, as well as the spatial location where the data were collected, are treated as integrated objects available in more than one format, such as comma separated value (CSV) text files and a shapefile. The CSV files with x,y coordinates can be easily added to any spreadsheet, database, GIS, or analytical software. The shapefile format can be used with most GIS systems.

Geodatabase -- The Jornada geodatabase runs ESRI ArcSDE spatial data engine on SQL Server 2008. The geodatabase provides storage and access to JRN spatial and tabular research data holdings. The geodatabase is also used to create and manage metadata in FGDC format which is subsequently used by the JRN website and geoportal to allow users to visualize, search, and access JRN GIS and tabular data. Map and image services are created from geodatabase resources, and are provided by the GIS server to the Geoportal and other web-mapping applications. This approach provides a visual display of the cataloged spatial datasets to the user. A geodatabase is used to integrate spatial and tabular research. Geographic coordinates, as well as other key dataset identifier fields, are inserted into CSV files to allow the data to be easily imported into any number of analytical software or databases.

Website, Data Catalogs, and Geoportals -- The JRN website provides access via a data catalog and geoportal to data as well as personnel information, publications, research proposals, reports, and other information about the Jornada and its research activities and collaborations. The website follows the LTER website design recommendations. Recently, the Jornada moved to a Drupal content management system to host websites for all JRN-related research projects and collaborations. The original JRN website is being moved into this combined website with implementation by the Drupal Environmental Information Management System (DEIMS) to support the data catalogs. DEIMS was initially developed by the LTER Network Office (LNO), and has been adopted by several other LTER sites (ARC, LUQ, NTL, NWT, PIE, SEV, VCR) as a common approach to making data available and for generating EML to LTER best practices, which will be harvested into the LTER Network Information System (NIS). EML generated by DEIMS is being harvested into the current LTER Data Portal (network-level metadata search engine).

We implemented ESRI open source geoportals into JIMS. The geoportals provide textual searches via keywords as well as the ability to query geographic extent and to map research site locations. Although primarily developed to facilitate the distribution of spatial datasets, the geoportal can also be used to query and deliver a wide range of products, including documents, tabular data, and integration with other data portals using web services. Registered users can save multiple search terms to revisit the site at a later date. Data providers can manually publish datasets in the portal or the geoportal can be configured to automatically publish datasets when properly formatted FGDC metadata are added or updated in a specific internal directory. The interface will also allow a user to select a bounding extent to limit or clip spatial datasets and automatically e-mail the customized files to the user as a zip file. The geoportal has the capability to deny access to restricted datasets or grant access to only selected registered users as defined by the portal administrator.

We plan on integrating Drupal and the geoportals to allow seamless access to both systems without requiring users to login separately to them. Currently, most JRN EML files in the LTER Data Portal point to the specific dataset location within the JRN data catalog on our old website (http://jornada-www.nmsu.edu). As GIS enabled data packages are created, the EML files are updated using Drupal to point to the data package.

(e) Networking and computing services. The Jornada site offices and laboratories located in Wooton Hall on the campus of NMSU are connected to a local area network (LAN) through a firewall to the NMSU network (Gigabit Ethernet). Most computers and all servers are connected to the LAN using Gigabit Ethernet (1000 Mb). We plan to increase bandwidth from the field station to the NMSU campus from 1.54 MB to 50-75 MB as soon as possible using high speed, multi-hop, point-to-point wireless radios. The increased bandwidth will support streaming data and video, and remote education activities (K-12) from the wireless network covering the research site. We plan to continue increasing the wireless coverage (cloud) across the research site to provide Wi-Fi and 900 MHz spread spectrum connectivity for researchers, educators, and scientific instrumentation.

Jornada servers support 2 resource pools: development and production. Each resource pool supports multiple virtual servers running multiple operating systems (Linux, Windows). The resource pools are configured to provide high availability and workload balancing to ensure the servers are available 24 hours a day, 365 days a year. If one of the physical servers (hypervisors) within a pool fails or is brought down for maintenance, the virtual servers running on the server are automatically transferred to another hypervisor. To a user connected to services provided by one of the virtual servers, the server will appear to have a slight delay (15-30 seconds), but otherwise the user will see no apparent effect from the virtual server being transferred to another hypervisor. Workload balancing allows virtual servers to be redistributed to other hypervisors in the resource pool to ensure optimal performance in the event a hypervisor starts to slow down due to workload. Currently, we have 4 physical servers within the production resource pool and 2 in the development pool. Additionally, servers that are not virtualized provide directory services (Active Directory, LDAP), backup, and workload balancing storage for the resource pools. Server storage is centralized using a storage area network (SAN) and provides 93 TB of storage capacity. The servers and SAN are connected redundantly to allow for hardware failure without impacting server performance.

Multiple forms of backup are incorporated to protect data and systems from disaster and to allow for rapid recovery in case a disaster occurs. Servers and switch closets are physically secured and environmentally controlled to provide security and protection. Differential backups are performed nightly on all servers and many desktop computers using a dual drive LTO 4 tape library directly attached to the SAN. Backup media is reused after 3 months. Backup media are stored off-site in case of catastrophe. Virtual server snapshots are performed prior to system upgrades or modifications to allow rapid recovery in the event these alterations produce undesirable results. The data archive volume is backed up routinely to DVDs and hard drives stored off-site. The DVDs are not reused, but are saved indefinitely. We are exploring mechanisms to automate and schedule server snapshots with little or no additional cost. We are also exploring disk-to-disk backups and alternative technologies to replace our tape library.

(f) Personnel. Our IM team consists of four full-time staff jointly supported by the JRN and USDA (Ken Ramsey: Information Manager; Jim Lenz: Network and systems administrator; Valerie LaPlante: Multimedia and Website Administrator; Scott Schrader: Geoportal Administrator). Student employees and graduate assistants support data entry and computer programming efforts. Team member's skill sets complement each other with some overlap to allow for temporary absence and employee turnover.

B. Milestones and deliverables relative to LTER network activities. Ongoing JRN participation in LTER network-wide activities includes the LTER Data Portal, All-Site Bibliography, and Climate databases as well as representation and participation at the annual Information Managers (IM) Meeting, IM Executive Committee, and NIS workshops. These activities are associated with expanding the capability of the JRN to acquire, maintain, and exchange information in a timely fashion to meet our milestones and deliverables (Fig. C2), and to share this information with other LTER and non-LTER users via the JRN website and the NIS being developed at the LNO.

Members of the JRN IM team are active participants in the NIS development. Ken Ramsey is participating in 3 NIS development tiger teams. Ken Ramsey and John Anderson are participating in 3 cross-site IM working groups (WG) to advance efforts to prepare site data and associated metadata for inclusion in the NIS: the SensorNIS WG is developing best practices for preparing near real-time streaming sensor data; the DEIMS WG is developing a common approach for creating EML; and the GeoNIS WG is developing best practices for inclusion of GIS and remote sensing data.

We continue to develop the EcoTrends website by adding datasets from > 50 sites within the US and abroad, deriving new data variables, and improving data accessibility and analytical tools. This web site was migrated from the LNO to a Jornada virtual server in LTER-V. The content was updated during this process to correct problems or omissions that had not been previously identified. We continue to develop the next iteration of the EcoTrends website and have dedicated 4 full-time staff and several students to this project. We plan on implementing the LTER NIS at the Jornada as soon as possible to explore integration of the new EcoTrends website with the data and metadata web services of the NIS. We are also integrating the P2ERLS website of general information (e.g., ecosystem type, long-term mean precipitation, temperature) from > 300 sites distributed globally (http://www.p2erls.net) with the EcoTrends website (http://www.ecotrends.info).

Recently, activity and discussion within the LTER Network resulted from the Bob Robbins video illustrating problems he encountered while trying to access data from each web site. JRN responded quickly to these problems by immediately implementing a website redirect to forward users to the current data catalog page. We then created EML using DEIMS to replace JRN EML documents used to search for our datasets on the LTER Data Portal. These documents now point directly to the appropriate dataset section of the data catalog. During this process, we increased the quantity of datasets in the LTER Data Portal as well as the quality and congruency of the EML metadata. As a member of the NIS Data Portal tiger team (Ramsey), we will continue to work with the LNO and the NIS developers to ensure that the current LTER Data Portal and planned LTER NIS Data Portal allow users to more easily access JRN datasets and associated metadata.

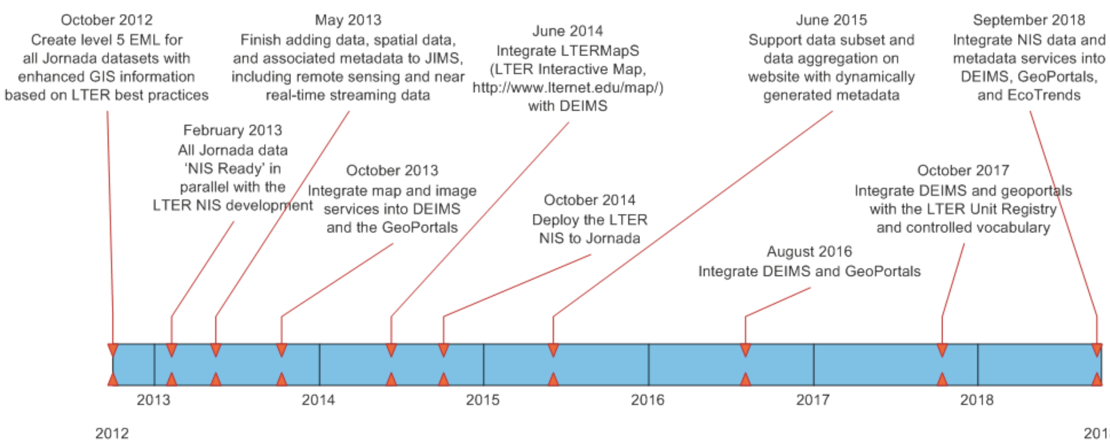

Fig. C2. JRN milestones and deliverables. NOTE: The term 'NIS Ready' indicates that the EML metadata are complete, accurately describe the related data file, and follow LTER best practices currently being defined by the LTER IMC as the NIS is developed by the LNO.

SUPPLEMENTARY DOCUMENTS

Postdoctoral Mentoring Plan

N/A

SUPPLEMENTARY DOCUMENTS

Table A.1. Core long-term and short-term studies and associated datasets.

Supplementary Table A1. Core long-term and short-term studies and associated datasets.**

Proposal study name (objectives)[1]	**Study**	**Responsible (Original) PI**	**Duration**	**Core areas**[2]	**Dataset name**[3] **(Variables measured)**	**Number of hits online**[4] **(requests**[5]**)**
CORE (SIGNATURE) LONG-TERM STUDIES AND ASSOCIATED DATASETS						
VEGETATION DYNAMICS						
VegMaps (Obj. 1-5)	Vegetation maps	Havstad (Gibbens)	1858, 1915, 1928, 1998	1	Vegetation maps (Dominant species or functional groups)	*
PermQuad (Obj. 1-5)	Permanent Chart Quadrat Data	Havstad	1915-	3,5	Cover of individual shrubs & perennial grasses (Basal/canopy area, perimeter of individuals)	USDA
			1915-	3,5	Density of perennial forbs	
LTER1_tran	Transect Plant Line Intercepts	Anderson (Cunningham)	1982-	1	Transect plant line intercepts - LT series (% cover) by species	143 (1)
LTER1_bound	East & West Boundary Fence Plant Line Intercepts	Anderson (Cunningham)	1982-1992	1	East & west boundary fence plant line intercepts - % cover for 9 species	47 (1)
			1986-	1,3	East & west boundary fence plant line intercepts - % cover for all species	32 (1)
NPP (Obj. 1-5)	Spatial and Temporal Patterns of Net Primary Production in Chihuahuan Desert Ecosystems (15 locations)	Peters (Huenneke)	1989-	1	Net primary production quadrat data (Cover, height by plant or plant part)	737 (2)
			1989-	1	Net primary production quadrat biomass data by species	529 (5)
			1989-	1	Annual ANPP, SUMMARY	40 (9)
			1989-	1	Net primary production reference harvest data (Height, cover, and dry weight by species)	525
		Anderson	1996-	5	Annual ground-based photos of 15 NPP locations	

Phenology (Obj. 3b)	Perennial Plant Phenology on NPP Locations	Peters (Huenneke)	1992-	1	Plant phenology transect at NPP locations (Monthly phenological stage of select species)	152 (3)
CCE (Obj. 2a)	Climate Change Experiment	Sala (Reichmann)	2006-	1,4	Soil water content in precipitation & nitrogren treatment plots at 2 depth profiles	
			2007	1,4	Plant cover in precipitation and nitrogen treatment plots by species	
	Climate Change Experiment: Response of mesquite and black grama to precipitation change	Throop	2007-2008	1,4	Photosynthetic rates for leaves from 5 precipitation treatments	
			2007-2008	1,4	Pre-dawn water potential for leaves from 5 precipitation treatments	
Xscale ConMod (Obj. 2b)	Cross-scale study	Peters	2008-	4	Conmod Pilot Study: Plant cover from plant line intercepts (Cover by species)	
			2008-	4	Conmod Pilot Study: Biannual repeat photography of conmod plots	
			2008-	4	Conmod Pilot Study: Quarterly BSNE sediment collection (Sediment weight collected at 2 heights)	
			2008-	4	Conmod Pilot Study: Monthly bedload (Total dry weight, % ash weight)	
CARBON AND NITROGEN						
TermBaits	Termite Baits	Anderson (Whitford)	1988-2000	2	Termite bait data (Loss of OM to termits)	69

LIDET *(Obj. 1)*	LTER Fine Litter Decomposition Experiment (LIDET): Above- and belowground decomposition of litter and roots over time (cross-site study)	Harmon	1990-2002	2	LTER Fine Litter Decomposition Experiment (LIDET) (Mass loss & nutrient concentrations of leaf litter, roots, & dowels)	Oregon State U
PLANT-ANIMAL INTERACTIONS						
StockRate *(Obj. 1-5)*	Livestock stocking rate	Havstad	1916-	3	Livestock abundance by pasture totaled for the Jornada (Animal unit months for cattle, horses, & sheep)	*
CLC *(Obj. 3)*	Valentines Creosotebush Lagomorph Study: perennial grass response to shrub removal, and lagomorph and cattle exclusion through time	Havstad (Valentine)	1938-	3	Line intercept data of long-term vegetation responses to shrub removal and lagomorph exclusion in a creosotebush community (Cover by species)	309
MSE *(Obj. 1a)*	Multiple Stressor Experiment: to examine effects of one-time pulse of seasonal livestock overgrazing and shrub removal on grass:shrub transitions	Havstad (Whitford)	1996-	3	Line-Point Intercept data on grazed & shrub removal plots (Cover by plant species)	USDA
		Okin (Virginia)	1996-	3	Annual small scale soil movement associated with mesquite shrubs & following shrub removal (Soil height at increasing distances from shrub center)	USDA
		Anderson	1997-	3	Annual ground-based photos of ungrazed/grazed and shrub-removal/unremoved plots	USDA

SMES (Obj. 5c)	Small Mammal Exclosure Study: To examine effects of exclusion of small mammals on plant species abundance through time	Schooley (Lightfoot)	1995-	5	SMES rabbit survey data (Species abundance)	27
			1995-	3	SMES vegetation quadrat data (Cover and height by species)	5
			1995-	3	SMES Cryptogam Crust Data (Cover of crusts)	16
			1995-	3	SMES Leaf Litter Data (Cover of litter)	16
			1995-	5	SMES Rabbit Feces Data (Number of feces)	16
			1995-	3	SMES Soil Surface Disturbance (Type, % cover, and vertical dimension of small mammal disturbance)	32
			1995-	5	SMES termite casing data (Dimensions of casing)	14
			1995-2005	3	SMES vegetation line intercept data (Species abundance & cover)	20
			1995-2007	5	SMES rodent trapping data (Species abundance)	51 (2)
Ecotone (Obj. 1, 2, 5c)	Ecotone study: to examine effects of small mammals on black grama recovery after disturbance across ecotones between black grama and mesquite	Bestelmeyer (Campanella)	2003-	5	Ecotone rodent trapping data (Species abundance)	*
			2003-	1	Ecotone plant biomass by functional group	*
			2003-	5	Ecotone rodent metrics (Species abundance, biomass, & energy)	*
AEOLIAN						
SoilMove (Obj. 1c)	Soil movement study across black grama-mesquite ecotones	Havstad (Gibbens)	1933-	3	Height of soil surface along grassland-shrubland ecotones	USDA
SCRAPE (Obj. 1c)	Crust Evolution	Okin (Gillette)	1995-	3	Abrasion of crust at Scrape Location (Soil height & hardness)	*

			1996-	3	Monthly photos of soil surface at 3 Scrape Site tower locations (3 soil surface closeups & 1 site overview photo)	*
DustFlux (Obj. 1-5)	Sediment collectors (BSNEs) at NPP locations and other locations	Okin (Gillette)	1998-	3	Quarterly horizontal sand mass flux data (BSNEs) at 15 NPP locations and Geomet location (Dust weights at 5 heights)	*
NEAT (Obj. 1b)	Nutrient and Ecosystem impacts of Aeolian Transport (NEAT) experiment	Okin	2004-	3	Horizontal sediment mass flux before & after the windy season from vegetation removal plots (Sediment weight at various heights)	*
		Throop/ Archer (Hewins)	2008-2012	2,4	Effect of soil deposition on litter decomposition (mass loss & litter ash weight)	*
HYDROLOGY						
Runoff (Obj. 5a)	Hydrology Natural Runoff Plots	Anderson (Ward)	1982-1994	4	Hydrology natural runoff plots - runoff (Runoff depth, suspended sediment concentration, precipitation, deposited sediment, and % organic carbon)	73
			1989-1990	3	Hydrology natural runoff plots plant cover by species	51
			1988-1990	4	Hydrology plot surface runoff water chemistry (Concentration of dissolved ions)	61
Ponds (Obj. 5a)	Stock ponds	Vivoni	2001-	4	Monthly surface water at instrumented stock ponds (Water height)	*
			2001-	4	Monthly repeat photography of instrumented stock ponds	*
TW (Obj. 5a, 5d)	Hydrometeorological Characterization of the Tromble Weir Watershed	Vivoni (Templeton)	2010-	3	Channel network flow at four locations in the Tromble Watershed (Water height & flow rate)	*

			2010-	3	Hydrological and energy surface and atmospheric fluxes in the Tromble Watershed (Wind speed, air temperature, atmospheric pressure, CO2 & H2O concentrations, & heat fluxes)	*
			2010-	3	Precipitation measured at four locations in the Tromble Watershed	*
			2010-	3	Soil moisture in the Tromble Watershed at 3 depths	*
			2010-	3	Soil temperature in the Tromble Watershed at 3 depths	*
CLIMATE, SOILS, AND ATMOSPHERE						
USDA_met (Obj. 1-5)	USDA Jornada Experimental Range Climate Data	Rango	1914-	3	USDA-NOAA Daily Climatological Data (Precipitation, max/min air temperature)	605 (1)
			1914-	3	USDA Monthly Summary Climatological Data (Precipitation, max/min air temperature)	122
			1953-1979	3	USDA Monthly Total Pan Evaporation Data	96
PPT_net (Obj. 1-5)	JER Standard Gauge Precipitation Data	Rango	1915-	3	JER standard gauge precipitation data	50 (2)
LTER1_swc	Transect Soil Water Content	Herrick (Wierenga)	1982-	4	Transect soil water content at 5 depths to 150 cm	356 (2)
			1982-	4	Transect soil water content as neutron count data at 5 depths to 150 cm	5
LTER_met (Obj. 1-5)	LTER Weather Station Climate Data	Rango	1983-	3	Daily summary climate data from LTER Weather Station (Wind Speed & direction, solar radiation, relative humidity, precipitation, air & soil temperature)	581 (6)

			1983-	3	Hourly summary climate data from LTER Weather Station (Wind Speed & direction, solar radiation, relative humidity, precipitation, air and soil temperature)	552 (6)
			1983-	3	Evaporation pan data (Jornada LTER)	98
			1992-	3	Dipstick rain gauge data - LTER Weather Station (Precipitation)	48
AtmDep	Atmospheric Deposition	Rango (Schlesinger)	1983-	4	Wetfall deposition chemistry data (Jornada LTER Weather Station) (NO3, NH4, Cl, SO4, Ca, Mg, Na, K, total N, & total P)	50 (5)
			1983-	4	Dryfall deposition chemistry data (Jornada LTER Weather Station) (NO3, NH4, Cl, SO4, Ca, Mg, Na, K, total N, & total P)	81 (5)
NPP_ppt (Obj. 1-5)	Monthly graduated rain gauge (GRG) precipitation at 15 NPP locations (LTER-II)	Rango	1989-	3	Monthly graduated rain gauge (GRG) precipitation at 15 NPP locations (LTER-II)	56 (7)
	Tipping bucket rain gauge precipitation - NPP locations	Rango	1999-	3	Precipitation: Tipping bucket rain gauge precipitation - NPP locations (LTER-III) (Timestamp for each 0.1 mm)	8
NPP_swc (Obj. 1-5)	NPP Soil Water Content	Duniway (Virginia)	1989-	4	NPP soil water content to 3m depth	252 (1)
			1989-	4	NPP soil water content as neutron count data to 3m depth	23 (1)
Biodiv_ppt	Biodiversity precipitation	Rango	1996-	3	Precipitation: Biodiversity tipping bucket rain gauge data - By Event (LTER-III) (Timestamp for each 0.1 mm)	39
			1996-	3	Biodiversity tipping bucket rain gauge data - Daily Summary (Precipitation)	53
GEOMORPHOLOGY						

SoilMaps (Obj. 1-6)	Maps of soil units	Monger	1918, 1963, 1980	6	Soil units	*
DesertSoils (Obj. 1-5)	Desert Soils Project	Monger (Gile)	1957-1972	6	Soils maps	*
DEM (Obj. 1-6)	Elevation maps	Monger		6	Elevation	*
Landform (Obj. 1-6)	Landform and geomorphology maps	Monger		6	Landform and geomorphology	*
LAND-ATMOSPHERE INTERACTIONS						
Jornex (Obj. 1-5)	Energy Balance	Rango	1995-	1,2	JORNEX vegetation transects (species & canopy height)	USDA
BowenRatio (Obj. 3d, 5d)	Carbon fluxes on eight US rangeland sites	Havstad	1996-2006	3	Jornada Bowen ratio data (Annual and monthly net ecosystem exchange of carbon; air temperature, concentrations of water vapor & CO2 in air; soil temperature, water content, bulk density, & heat flux)	USDA
CBC (EddyFlux) (Obj. 3b, 5d)	Eddy flux tower data on creosotebush bajada location	Tweedie	2010-	4	Meteorological data from eddy flux tower (Pressure, air temp, relative humidity, precip, wind speed & direction)	U Texas-El Paso
			2010-	1	Hourly phenology photos for determination of greenness (Digital photo)	
MANAGEMENT PRACTICES						
ShrubControl (Obj. 1-5)	Shrub control treatments	Havstad	1912-	3,5	Shrub control treatments	USDA
Exclosures (Obj. 1-5)	Livestock exclosures	Havstad	1912-	3,5	Livestock exclosures	USDA

Regional LandCover (Obj. 6)	Social-ecological dynamics of rangelands of the Chihuahuan Desert	Skaggs	1936-1940	3	Historical vegetation maps of public grazing lands in southwestern New Mexico	BLM
County LandCover (Obj. 6)	Remote sensing assessment of land cover change in the Mesilla Valley, NM	Buenemann (Hestir)	1985-2009	3	Land cover classification	*
IMAGERY						
(Obj. 1-6)	Ground-based photos	Rango	1912-	1-5	Ground-based photos	USDA
(Obj. 1-6)	Aerial photos	Rango	1936-	1,3,5	Aerial photos	USDA
(Obj. 1-6)	Landsat & NOAA AVHRR	Rango	1972-	1,3,5	Landsat & NOAA AVHRR	USDA
(Obj. 1-5)	UAV photos	Rango	2004-	1,3,5	UAV photos	USDA
Proposal study name (objectives)[6]	**Study**	**Responsible (Original) PI**	**Duration**	**Core areas**	**Dataset name (Variables measured)**	**Number of hits online (requests)**
SHORT-TERM STUDIES AND ASSOCIATED DATASETS						
VEGETATION DYNAMICS						
	Mesquite Phenology Study	Anderson (Virginia)	1986	4	Mesquite Phenology Study: Mesquite Tissue Nutrients - 1986 (N & P)	46
			1987	4	Mesquite Phenology Study: Mesquite Tissue Nutrients - 1987 (N & P)	50
			1987	5	Mesquite Phenology Study: Mesquite Soil Mites (Abundance)	91
			1987	4	Mesquite Phenology Study: Mesquite Root Tube Soil Nutrients (NO3 & NH4, %H2O)	49
			1988	5	Mesquite Phenology Study: Soil Nematodes (Abundance)	59
			1988	5	Mesquite Phenology Study: Mesquite foliar arthropods (Abundance)	47

			1988	5	Mesquite Phenology Study: Mesquite Phenology (Phenology componenets)	44
			1988-1989	5	Mesquite Phenology Study: Surface soil microarthropods (Abundance)	68
			1988-1989	4	Mesquite Phenology Study: Plant nutrient analysis (Concentrations of N, P, Zn, Cu, Fe, & Mn)	85
			1988-1989	5	Mesquite Phenology Study: Mesquite nodulating rhizobia (Abundance)	73
			1988-1989	4	Mesquite Phenology Study: Soil Nutrients (Concentrations of N, PO4, Zn, Cu, Fe, & Mn)	89
	Transect Creosote Leaf Area Study	Anderson (Whitford)	1986	5	Transect Larrea Leaf Area (Leaf weight-per-unit area)	
	Transect Vegetation Biomass	Anderson (Whitford)	1989	5	Transect Vegetation Biomass of herbaceous	58
			1989	2,4	Transect Soil Mineralization Potential (Field) (N-mineralization potential)	52
			1989	2,4	Transect Soil Mineralization Potential (Initial) (N-mineralization potential)	60
	Ecosystem Effects of Plant Diversity (Biodiversity Experiment)	Anderson (Huenneke)	1995	3,5	Biodiversity study: Biomass removal, initiation of experiment (Dry mass removed by plant growth form)	52
			1996-1999	2,3	Biodiversity study: Soil erosion pan (Weight of surface sediments by category)	32
			1997	5	The effects of changing vegetative composition on the abundance, species diversity and activity of birds in the Chihuahuan Desert (LTER-III) (Bird species and activity type)	58

			1997-2004	5	Biodiversity study: Vegetation transects (Diameters and height by species)	250
			1998	2,3,5	Biodiversity study: Erosion zone vegetation (Plant cover and volume)	79
			1999	5	Biodiversity study: Biodiversity plant response, Summer 1999 (Diameters and height by species)	28
	Drought recovery of Larrea tridentata	Anderson (Gutschick)	1996-2000	4	Drought recovery gas-exchange (Leaf stomatal conductance, internal CO2 concentration, & temperature)	97
	Arson burn on LTER-I Transect Plant Line Intercepts	Anderson (Huenneke)	2000	5	Arson burn on LTER-I Transect plant line intercepts - LT series (% cover) (Average by species)	38
			2000	5	Arson burn on LTER-I Transect plant line intercepts - field data (tape format) (Cover by species)	
CARBON, NITROGEN, MICRONUTRIENTS						
	Transect Soil Physics	Anderson (Nash)	1982-84	4	Transect soil particle size analysis	46
		Anderson (Fisher)	1985	4	Transect soil cations (Concentrations)	26
			1985-86	4	Transect soil phosphate (Concentration)	38
			1985-86	4	Transect total nitrogen in soil	39
	Transect Soil Nitrogen	Anderson (Fisher)	1983-86	4	Transect Soil Nitrogen (N concentrations in NO3, NO2, and NH4)	17
	Transect Litter Collection Study	Anderson (Whitford)	1985-1988	2	Transect creosote litterfall (Biomass)	44
			1985-1988	2	Transect mesquite litterfall (Biomass)	45
	Fluffgrass: Microarthropod effects on nitrogen availability	Anderson (Silva)	1986	4	Fluffgrass plant total nitrogen and biomass	44
			1986	5	Fluffgrass plant growth (Growth responses to treatments)	33

			1986-1987	4,5	Fluffgrass mesocosm: mites and nematodes (Total & microbial N availability)	46
			1986-1987	5	Mesocosm microarthropod numbers	40
			1986-1987	4	Fluffgrass anion exchange resins bags for NO3 (NO3 availability)	36
			1986-1987	4	Fluffgrass cation exchange resin bags for NH4 (NH4 availability)	27
			1986-1987	5	Fluffgrass plant dynamics (Plant diameter; mite & nematode soil weight; root weight, root total N, nematode abundance)	26
			1986-1987	4	Fluffgrass soil total nitrogen in rhizosphere	39
	Grama/Mesquite Leaching Mineralization Potential Survey	Anderson (Fisher)	1986	4	Grama/Mesquite Leaching Mineralization Potential Survey (Soil inorganic N)	34
	Mesquite Soil Cores	Anderson (Virginia)	1986	5	Mesquite Soil Cores: Deep Soil Microarthropods (Abundance)	41
			1986	4	Mesquite Soil Cores: Deep Soil Core Micronutrients (Zn, Cu, Fe, & Mn concentrations)	45
			1986	4	Mesquite Soil Cores: Deep Soil Core N-Mineralization (N-mineralization potential)	40
			1986	4	Mesquite Soil Cores: Deep Soil Core Nutrients (P & N concentrations; root biomass; VAM, & rhizobia abundance)	46
			1986	4	Mesquite Soil Cores: Deep Core Soil Saturation Extracts (Cations, carbon, & sulfate concentrations)	39

			1986	5	Mesquite Soil Cores: Surface Soil Microarthropods (Taxonomy and abundance at 2 depths)	72
			1986	4	Mesquite Soil Cores: Surface Soil Nematodes (Abundance by guild)	62
			1986	4	Mesquite Soil Cores: Surface Soil Nutrients (Soil nutrients, root biomass, & minteralization potential)	43
			1986	4	Mesquite Soil Cores: Surface Soil Canopy Position Nutrients (Soil N concentrations under shrubs)	47
	Transect Root Decomposition	Anderson (Mun)	1986-1990	2,4	Root chemistry (Concentrations of tannin, lignin, carbohydrates, N, H2O & acid solubles, non-polar substance)	32
			1986-1990	2,4	Root chemistry raw data (Concentrations of tannin, lignin, carbohydrates, N, H2O & acid solubles, non-polar substance)	38
			1986-1990	2	Root weight (Initial and remaining weight)	42
	Ammonia Volatilization	Anderson (Schlesinger)	1988	4	Nitrogen volatilized as ammonia -- 1988	88
			1989	4	Nitrogen volatilized as ammonia -- 1989	43
	Plant Nutrient Distribution In Long-Term NPP Plots	Anderson (Virginia)	1989-1990	1,4	Plant nutrient distribution beneath and between plant canopies in the mesquite, grassland, playa, creosotebush, and tarbush plant communities (Total N & P)	43
	Soil Nutrient Distribution In Long-Term NPP Plots	Anderson (Virginia)	1989	4	Soil Nutrient Distribution In Long-Term NPP Plots - 1989 (pH, CaCO3, P, NH4, NO3, Total N, cations, micronutrients)	42

			1991	4	Soil Nutrient Distribution In Long-Term NPP Plots - 1991 (Saturation%, Total N, pH, %H2O)	47
PLANT-ANIMAL INTERACTIONS						
	Transect Termites (LTER-I)	Anderson (Conley)	1982-1986	2	Transect termites (Abundance)	103
	Jornada Grasshopper and Vegetation Study	Anderson (Lightfoot)	1983-1985	5	Jornada Grasshopper Data (Age/sex; substrate)	63
			1983-1985	5	Jornada grasshopper plot herbaceous vegetation data (Annual abundance)	68
	Transect Leaf-litter Microarthropods	Anderson (Cepeda)	1984-1985	5	Transect leaf-litter microarthropod data (Species abundance)	40
	Arthropod species composition from LVAR creosotebush study	Anderson (Lightfoot)	1985-1986	5	Arthropod trophic group composition data (Species abundance)	83
			1985-1986	5	Arthropod species composition from LVAR creosotebush study (Species abundance of common species)	93
	Transect Soil Disturbance (LTER-I)	Anderson (Whitford)	1986	3	Transect soil disturbance (Disturbed area by animal category)	37
	Transect Rabbit Herbage Wastage	Anderson (Whitford)	1986-1989	2	Rabbit browsed plant biomass (Dry weight by species)	57
			1986-1987	2	Rabbit browse total nitrogen by browsed plant species	98
			1986-1989	2	Rabbit Pellet Biomass (LTER-I) (Dry weight)	56
			1986-1987	2	Rabbit pellet total nitrogen (LTER-I)	74
	Effects of harvester ant nests on soil properties and vegetation	Anderson (DiMarco)	1987	3	Density & cover of winter annual plants	74
			1987	3,4	Ant nest soil nutrients (Nest biomass; N, P, and cation concentrations)	65
			1987	2	Ant nest soil organic matter (%)	56

			1987	3,4	Ant nest soil water content	65
	Animal Transects	Anderson (Lightfoot)	1989-1994	5	Animal transect (Population densities of rabbit & bird)	117
	Arthropod Pitfall Traps-II	Anderson (Lightfoot)	1989-1994	5	Arthropod pitfall trap data (LTER-II) (Species abundance)	15 (1)
	Lizard Pitfall Traps	Anderson (Lightfoot)	1989-2006	5	Lizard pitfall trap data (Species, morphological measurements)	24
	Small Mammal Trapping (LTER-II)	Anderson (Whitford)	1990	5	Small mammal trapping (LTER-II) (Species, morphological measurements)	104
	Arthropod Pitfall Traps-III	Anderson (Lightfoot)	1995-2000	5	Arthropod pitfall trap-III (Species abundance)	12 (1)
HYDROLOGY						
	Nutrient losses in runoff from grassland and shrubland habitats: I. Rainfall simulation experiments	Anderson (Schlesinger)	1995-1996	3,4	Nitrogen and phosphorus chemistry (Dissolved N & P)	98
			1995-1996	3,4	SUMMARY of grassland nitrogen and phosphorus chemistry (Dissolved N & P)	68
			1995-1996	3,4	SUMMARY of intershrub nitrogen and phosphorus chemistry (Dissolved N & P)	68
			1995-1996	3,4	SUMMARY of shrub nitrogen and phosphorus chemistry (Dissolved N & P)	70
CLIMATE, SOILS, AND ATMOSPHERE						
	Upper Trailer Soil Temperature	Anderson (Whitford)	1980-1986	3	Upper Trailer soil temperature (LTER-I) at 5 cm and 20 cm depth	37
	Transect Precipitation	Anderson (Ludwig)	1982-1986	3	Transect precipitation (weekly)	59
	Transect Soil Water Potential	Anderson (Whitford)	1986-87	4	Transect Soil Water Potential 1986 - 1987 (& soil temperature)	133
			1988	4	Transect Soil Water Potential - 1988 (& soil temperature)	33

[1] Study name and objectives in LTER-VI proposal.

[2] Core Areas: 1) primary production; 2) organic matter accumulation in surface layers; 3) disturbances; 4) inorganic inputs and movements of nutrients through soils; 5) populations selected to represent trophic structure

[3] Datasets continue to be added to online catalog

[4] Number of times a data file associated with a dataset was accessed online from Jan 2007 – Dec 2011.
There is an approximately 13 month gap (21.6%) in access logs (07/2010 - 08/2011) resulting from server migration in 2010.
Numbers have been adjusted to excluded website crawlers (autoharvesting robots), which usually increased numbers 10 fold.
Non-LTER owned datasets (e.g., Utah State U, USDA) may be restricted but accessible through the appropriate agency.
Link to Data web access statistics by domain, data type, and core area

[5] Number of times a data file associated with a dataset was requested from the information management team from 11/01/2006 - 1/31/2012.

[6] Short-term studies are not cited in the LTER-VI proposal.

* Access via PI is not tracked by the JRN information management team.

** Table with hotlinks available at http://jornada-www.nmsu.edu/renewal_2012/A-Suppl_TableA1.pdf

SUPPLEMENTARY DOCUMENTS

Site management plan

Our organizational structure includes 1 lead PI, 17 co-investigators, a 6-member Executive Committee (JRN-EC), 6 fulltime NMSU and 13 USDA staff, and a large number of temporary employees (NMSU undergraduates) (Fig. B1). Our co-investigators are strategically selected through time for their expertise, experience, interest in working collaboratively, and dedication to long-term research and data accessibility (e.g., all PIs have ≥1 core long-term dataset online; Table A1). As a result, our group includes faculty from both local (NMSU) and nationally distributed universities (Arizona State Univ. [ASU], Univ. Arizona [UA], Univ. Illinois [UI], Univ. Texas at El Paso [UTEP], Univ. California at Los Angeles [UCLA], Univ. of California at Berkeley [UCB]) as well as scientists from two federal agencies (USDA, USGS). Each investigator has a clear role in the overall project, and participates in specific studies depending on her/his interest and the expertise needed for a question. Interactions among investigators occur informally when needed, and formally at our annual PI meeting held in conjunction with our annual Jornada symposium. Resources available to investigators include technician support, supplies, site-based travel, and salary for site-level infrastructure. Formal assessments of progress are made at least every other year. Reallocation of funds is based on: productivity (i.e., quantity/quality of journal papers); leveraging of outside funding; collaboration with team members; graduate student involvement; submission of datasets to our information management system; cross-site and network-level involvement.

Collaborative, dynamic approach. Our philosophy is based on collaboration such that research teams are dynamic and form as needed for specific questions rather then being static through time. This collaborative structure is an important mechanism for stimulating discussion of research plans and results, charting progress, and collectively identifying emerging topics and trends. The majority of resources not allocated to site-based infrastructure are provided to teams in the form of shared M.S. graduate students at NMSU. We successfully used this approach in LTER-V with a focus on PhD students. In LTER-VI, we will prioritize M.S. students because they are better suited to the studies proposed here, and to maximize the number of students and investigators directly involved in JRN-funded projects. Prioritizing NMSU students will optimize resources by reducing overhead and out-of-state travel costs, and will allow greater opportunities for minority students from this Hispanic-serving institution to participate. We will continue to provide partial support for Ph.D. students funded by other sources, such as teaching assistantships and other awards. Selection of projects for LTER student funding will be determined through a competitive process. Teams will submit a justification, rationale, and expected products, as well as outcomes from previous student funding, for each request to the JRN-EC for evaluation and prioritization.

Communication. Since early in LTER II, Jornada researchers from multiple institutions have had to devise ways to communicate effectively. Our annual Jornada Symposium, initiated in 1990, remains one of our most important venues for communication. Although attendees include many other scientists and students (>150 for the past several years), a 1-2 day co-investigator meeting occurs the same week. We also use teleconferencing for discussions involving local and non-local investigators. Peters edits our periodic newsletter, the *Jornada Trails*, which reaches > 300 subscribers, and is available on our web page (http://jornada.nmsu.edu).

Leadership continuity and administration. We continue our pattern of evolutionary change in project leadership and scientific personnel that began in 1982. Debra Peters continues as lead PI, a role she took over in 2003 following the departure of Laura Huenneke to the University of Northern Arizona. Walt Whitford (PI during LTER I), Bill Schlesinger (PI during LTER II-III), and Laura Huenneke (PI during the first half of LTER IV) continue their involvement in our scientific program. Peters as lead PI provides overall project leadership. She is the principal contact for NSF, the LTER Network Office, NMSU, and collaborating scientists. She has overall responsibility for coordinating sampling activities, data management, site promotion, and baseline analyses. She also prepares annual report and supplemental proposals, and attends the annual LTER Science Council meetings. Peters along with K. Havstad (USDA), C. Monger (NMSU), B. Bestelmeyer (USDA), G. Okin (UCLA), and E. Vivoni (ASU) comprise the JRN-EC with ultimate authority in decisions of allocating resources and setting policies. Our commitment to education is reflected by the inclusion of S. Bestelmeyer, the coordinator of our Schoolyard LTER program and director of our partner, the non-profit Asombro Institute for Science Education (AISE), as a coPI on our proposal cover page. Our site manager, John Anderson, makes decisions about the use of lab, office, and field facilities by visiting and local researchers, and consults with the JRN-EC as needed. Instead of an external Advisory Committee with limited number and diversity of members, we have developed ca. two-dozen specific cooperative research agreements with a cross-section of clients and stakeholders to provide more effective two-way communication and collaboration. Havstad, Herrick, and B. Bestelmeyer (USDA), and Duniway (USGS) serve as liaisons with local, regional, national, and international agencies and institutions. Monger serves as a liaison with NMSU's College of Agriculture and the NM Agricultural Experiment Station. S. Bestelmeyer serves a similar role with the College of Arts and Sciences. Skaggs provides liaisons with planners for the city of Las Cruces and Doña Ana County.

Succession planning. We plan for unexpected changes in leadership through a level of redundancy: the JRN supports travel for at least one additional co-PI to attend each Science Council meeting, we promote active involvement by co-PIs in each LTER All Scientists meeting and network-level workshops, and the JRN-EC is involved in all major JRN program-level decisions. Long-term change in leadership takes time to train a lead PI in all aspects of the program. The Jornada USDA is expected to fill several open positions within the next 3-5 years, and we will use these positions as opportunities to recruit and train a future lead PI. We do not expect appropriate faculty openings at NMSU in the same time period.

Recruitment and diversity. Given resource limitations of LTER, we are very strategic in recruitment of new members to our research team. Our approach to fill major gaps in knowledge and expertise is through active recruitment of investigators as the need arises, and to seek diversity in gender, expertise, and ethnicity. We will continue this approach that has been very successful in both building our research group and dealing with turnover. For example, of the 12 JRN investigators in 1997, only two are current members (Monger, Havstad). In 1997, only 3 investigators were local (NMSU, USDA) whereas our team now includes 5 NMSU faculty and 5 USDA scientists. In LTER-V (2006-2012), we added two senior scientists with international expertise in aridlands (a grassland ecosystems ecologist, Osvaldo Sala [ASU], and a shrub ecophysiologist, Steve Archer [UA]). We also added an aridland hydrologist (Enrique Vivoni [ASU]), a soil scientist (Mike Duniway [USGS]), and an expert in UAVs (Andrea Laliberte [NMSU]). In LTER-VI, we propose to add three co-investigators, each with different expertise to increase both our ecological depth and breadth: Nathan Sayre (social scientist, UCB), Robert Schooley (animal ecologist, UI), and Craig Tweedie (cyberinfrastructure and wireless technology, UTEP). We continue our strong bi-college involvement at NMSU with 2 full-time and 2 affiliate faculty in the College of Arts & Sciences, and 2 full-time and 2 affiliate faculty in the College of Agriculture. We also have two affiliate faculty with joint appointments in both colleges. Our investigators include two Hispanics, and 5 females and 14 males. We will continue to attract and retain minority students, particularly Latino students, through NMSU, UTEP, UA, and ASU as Hispanic-serving institutions.

Integration of non-LTER scientists. We actively integrate non-LTER scientists into our program through collaborative projects, some are co-funded by the JRN and others are supported by other sources. We have a large number of collaborators in state and federal agencies as well as other countries, as indicated by co-authors in our publications. Our key local collaborators are Donovan Bailey (grass genetics), Michaela Buenemann (landuse/cover modeling), and Sam Fernald (hydrologist) at NMSU; Dawn Browning (phenology) with the USDA, and Joel Brown with the NRCS. As a result of our recently funded Macrosystems Project ((EF-1065699), we are forming new collaborations with non-LTER scientists with skills in large-scale spatial analysis, and interests in regional and cross-site comparisons (e.g., Julio Betancourt, Tom Swetnam, Russ Monson, Xubin Zeng, Chris Castro). We will actively promote further collaborations with this group and the JRN, and will recruit additional macro-ecologists as funding is available.

Integration of non-LTER technical staff. The USDA provides access to 5 full time technical staff based at the field site to provide routine support, housing, field offices, and emergency assistance to collaborators and students at no cost. Within Wooton Hall, the USDA provides access to an additional 8 full time technical and professional staff to provide GIS, data management, field research, data analyses, and office support to PIs, collaborators, and students at no cost to the LTER.

LTER-USDA site collaboration. The USDA continues to provide support in terms of salaries for federal scientists and support staff, and field support (e.g., on-site security, on-site facilities, vehicles, on-site assistance). Office and laboratory facilities are located in the USDA Wooton building on the NMSU campus without cost to NMSU or LTER. Field sites are located on the USDA-Jornada Experimental Range and the adjacent NMSU-Chihuahuan Desert Rangeland Research Center (CDRRC). These properties located within 30 km of NMSU represent >100,000 ha dedicated to long-term and experimental research. Researchers have access to field-oriented laboratory facilities at the USDA headquarters on-site with reliable network access and a water storage system as well as trailers for overnight stays. NMSU and USDA provide cell phones available for check out by researchers and students to enable emergency contact with campus and emergency personnel when in the field. A collaborative effort with the USDA is adding wireless connectivity to sensors, such as rain gauges and flumes, as funding permits.

Fig. B1. Our Jornada LTER research team includes 18 investigators, 19 staff, and 5 local collaborators.